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ADVANCED
GRINDING PRACTICE

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ADVANCED GRINDING PRACTICE

A TREATISE ON PRECISION GRINDING
METHODS AND THE EQUIPMENT USED
IN MODERN GRINDING PRACTICE

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PREFACE

THE grinding of duplicate machine parts efficiently was impossible during the earlier stages of grinding practice, because only light machines and slow-cutting wheels were available; but this condition has been changed by the development of artificial abrasives, improved bonding processes, and powerful machines that make it possible to use the fast-cutting modern wheels effectively in the production of precision work. Therefore, successful grinding practice now depends mainly upon the way in which this high-grade equipment is used. The machine may be perfect and the wheel faultless as to cutting qualities, but to grind successfully, it is necessary to follow approved methods.

Much has been published regarding the constructional features of different types and designs of grinding machines, but there has been a lack of definite information on modern grinding practice. This treatise deals almost exclusively with subjects of especial value to the *user* of grinding machines. The chapters on "Cylindrical Grinding," "Form Grinding," "Internal Grinding," "Surface Grinding," "Cylinder Grinding," "Crankshaft and Camshaft Grinding" and "Disk Grinding," all contain information that is fundamental and of practical value to the man in the shop. Throughout the book there are many typical examples which indicate what *can* be done, by showing what *has* been done. These examples are accompanied by data arranged in compact form and covering wheel and work speeds, grade and grain of wheels used, and other important points.

Careful attention has been given to the subject of grinding wheel selection, and the tables accompanying this chapter list the grain and grade of wheels recommended by various wheel manufacturers for grinding different materials. While such information must necessarily be general, it will often serve as a guide and enable efficient results to be obtained without needless experimenting. Various types of wheel-truing devices and fixtures for holding work on different classes of machines are also described and illustrated in separate chapters.

The aim has been to present useful information and to exclude unimportant details. It is not expected that the practice described will invariably meet with approval, since opinions differ greatly in regard to grinding methods. A special effort has been made, however, to present average practice, and to show exactly how various classes of work are ground in different shops.

The coöperation of various automobile, grinding machine and wheel manufacturers, in supplying illustrations and data, has greatly increased the value of this treatise.

THE AUTHORS.

NEW YORK, *October, 1915.*

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ADVANCED GRINDING PRACTICE

CHAPTER I

CYLINDRICAL GRINDING

Grinding machines were originally used almost exclusively for truing tool steel parts which had been distorted by hardening, and they are still indispensable for work of this class. The great improvements which have been made, both in grinding machines and abrasive wheels, however, have resulted in the application of the grinding process to the finishing of a great many unhardened parts. In either case, the work, as a rule, is first reduced to nearly the required size by turning in some form of lathe, and then it is ground to the finished dimension. After a part has been hardened, grinding is the only practicable method of truing it. On the other hand, unhardened pieces can be finished by other means, but grinding is preferable for most cylindrical work, because it enables parts to be finished accurately to a given diameter in less time than would be required by any other known method.

Several different types of grinding machines have been developed for handling the various kinds of work to which the grinding process is applicable. The machines used for grinding cylindrical parts such as shafts, piston-rods, etc., are called cylindrical grinders, whereas the type used for grinding holes in bushings, gears, milling cutters, etc., are known as internal grinders. There are also surface grinders for finishing flat or plane surfaces, and, in addition, types that are specially designed for sharpening cutters, reamers, etc. As cylindrical grinders are the type most commonly used, they will be considered first.

Principle of Cylindrical Grinding Process. — When grinding a cylindrical part, such as a rod or shaft, it is mounted between the conical centers of the grinder (as shown by the diagrams, Fig. 1), just as it would be placed between the centers of a lathe for turning; in fact, the same center holes upon which the shaft was rough-turned are used when grinding. The work is rotated rather slowly upon these centers c and c_1 by a driving dog d, which engages a pin in the driver plate at the left, and the surface is ground cylindrical by a disk-shaped wheel g. This wheel rotates rapidly (a 14-inch wheel would run about 1600 revolutions per minute), and the grinding is done either by traversing the

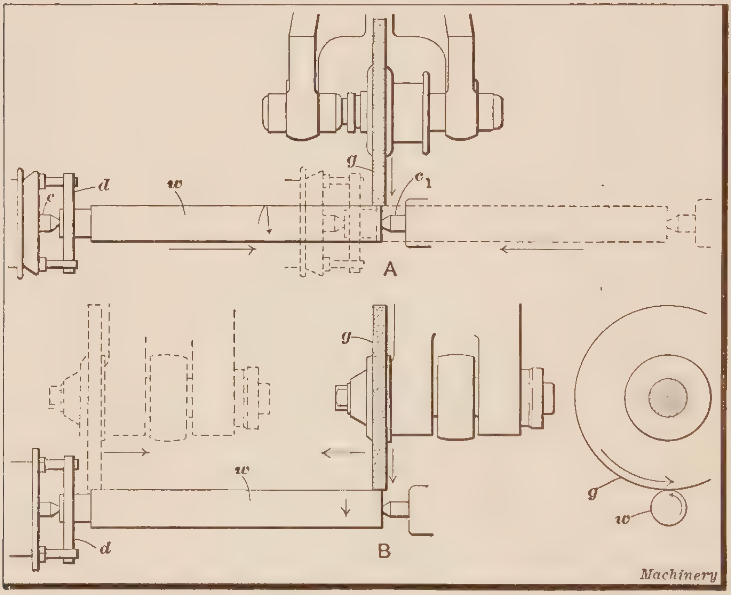


Fig. 1. (A) Diagram illustrating Method of Grinding by Traversing Work Past Face of Grinding Wheel. (B) Grinding by Traversing the Wheel

rotating part past the face of the wheel or by traversing the wheel along the work. Some cylindrical grinders operate in one way, and some the other. The diagram A illustrates the method of grinding by traversing the work, the reciprocating movement past the wheel-face being indicated by the full and dotted lines, which show the position of the shaft at each end of the stroke. The revolving wheel g is fed inward a slight amount at each end of the work and the latter is accurately ground to the required diameter. The wheel can be fed by hand or automatically, the latter method being generally employed, except when adjusting the wheel or starting a cut. The amount that the part being ground moves endwise, while making one revolution, is always somewhat less than the full width of the grinding wheel-face, in order to secure a smooth surface free from ridges. This side traverse, as well as the rotative speed of the work, is varied to suit conditions. The operation of a machine having a traversing wheel is shown by diagram *B*. In this case, the work, instead of moving back and forth past the wheel, rotates in one position while the grinding wheel, which is mounted on a suitable carriage, moves from one end to the other, as indicated by the full and dotted lines.

The grinding wheels are composed of innumerable grains of some hard abrasive material which is held together by an adhesive bond. These grains or cutters, as they might properly be called, have sharp corners or edges which cut away the metal as the work traverses past the wheel-face, or *vice versa*. The relative rotation of the wheel and the part being ground should always be as shown by the end view (diagram *B*), for cylindrical grinding. As the arrows indicate, the grinding side of the wheel *g* moves downward, and that side of the work *w* being ground moves upward or in the opposite direction.

A Cylindrical Grinding Machine. — From the foregoing, it will be seen that a cylindrical grinding machine must be arranged to rotate both the grinding wheel and work. In addition, either the work or the wheel must be traversed longitudinally. The wheel must also be fed in automatically for taking successive cuts, and provision must be made for varying the traversing movement and the rotative speed of the work to suit different conditions. The way these various movements and adjustments are obtained with the type of cylindrical grinder illustrated in Fig. 2 will be explained. It should be understood, however, that the mechanical details vary with grinders of different makes, although all cylindrical grinding machines operate on the same general principle. Other machines for cylindrical grinding will be referred to later.

The machine shown in Fig. 2 operates by traversing the work past the grinding wheel *G*, as illustrated by the diagram *A*, Fig. 1. The grinding wheel is revolved by a belt that passes over a pulley at the side of the wheel and connects with an overhead countershaft. The table *A*, which moves back and forth when the machine is in operation, carries a headstock *H* and a footstock *F* in which conical centers C and C_1 are inserted. When a cylindrical part such as a shaft or rod is to be ground, it is placed between these centers and is rotated upon them by a belt passing over pulley *B* and connecting with a long cylindrical drum, which forms part of the overhead works for driving the machine. This long drum is used instead of a narrow pulley, so that the belt can shift along as the table moves to and fro.

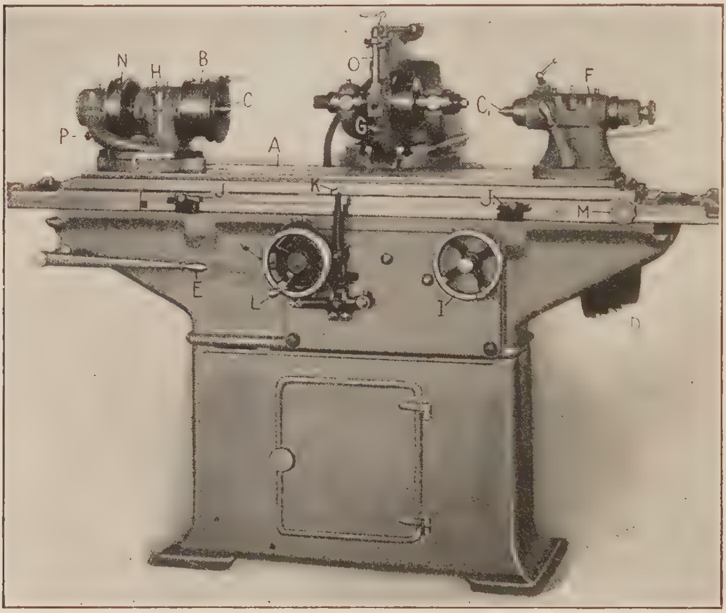


Fig. 2. Brown & Sharpe Cylindrical Grinding Machine of Universal Type

The power for moving the table along the ways of the bed is obtained from a belt connecting with cone-pulley *D* which transmits motion to the table through suitable shafts and gearing located inside the bed. The traverse of the table and rotation of the work-spindle can be started or stopped by lever *E* to the left. The wheel *I* to the right is used for moving the table by hand. When operating the table in this way, the knob in the center of this wheel is pushed inward, and when the table is to be traversed automatically, this knob is pulled out. The travel of the table or the length of its stroke is controlled by the position of the adjustable dogs *J* and J_1 which operate the reversing lever *K*. Lever *K* connects with a clutch inside the base, and this clutch, through gearing, reverses the movement of the table whenever lever *K* is thrown to the right or left. The length of the stroke is changed by varying the distance between dogs *J*. These dogs slide upon a rack attached to the front of the table and are held in position by a spring-latch that engages the rack teeth.

The usual method of grinding a cylindrical part is to rotate it on two "dead centers," both centers remaining stationary. The object of grinding work while it revolves on stationary centers is to secure accuracy, for then any slight error which may be in the spindle bearings is not reproduced in the work. If center *C* were rotated with the work, as in the case of a lathe, any eccentricity of the center would result in inaccurate grinding. Therefore, when grinding cylindrical parts on centers, the spindle is locked by a pin *P* which engages a hole in the flange of pulley *N*. Pulley *B*, which rotates freely around the spindle, carries a driving dog and rotates the work. For some classes of grinding, as, for example, when grinding parts held in a chuck attached to the spindle, it is necessary to rotate the spindle. Lock-pin *P* is then withdrawn and a belt from the overhead driving drum is connected with pulley *N*. The upper part of the work-table can be set at an angle for taper grinding.

The Automatic Cross Feed. — The grinding wheel can be moved to or from the work by rotating handwheel *L* (Fig. 2), and it is fed inward automatically by the mechanism located just back of this wheel. This mechanism is so arranged that it can be set to stop the feed when the diameter has been ground to a predetermined size. The way in which this automatic feed operates will be more clearly understood by referring to the detail drawing, Fig. 3. When the stroke dogs *J* strike lever *K*, thus reversing the table movement, the lever *G* is also actuated, and it has a V-shaped end which engages roll *h*, and operates lever *H* and pawl *P*. If this pawl is in mesh with the ratchet wheel *W*, the grinding wheel will be fed forward an amount depending upon the position of the screws *F*, which come against a surface on lever *G*, thus regulating the upward movement of lever *H*, and, consequently, the movement of the pawl at the end of each stroke. The automatic feed will continue at each reversal until the shield *M* (which is attached to head *N*) intercepts pawl *P* and prevents it from engaging the ratchet wheel *W*. The feed then stops automatically.

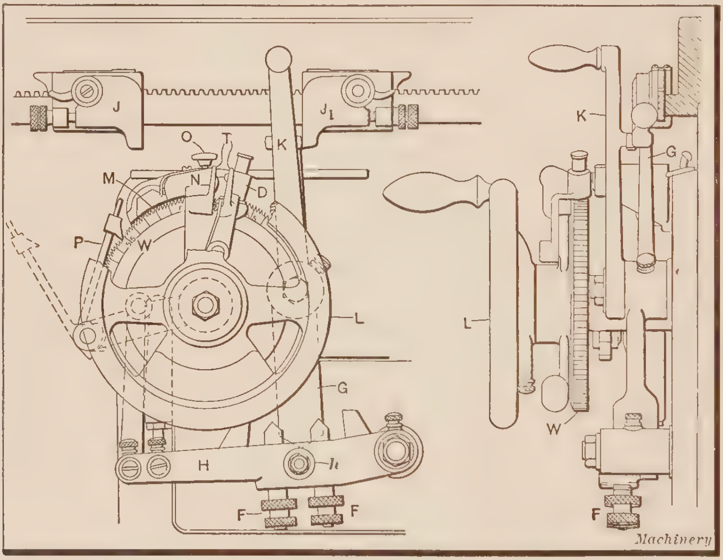


Fig. 3. Mechanism for Feeding Grinding Wheel Forward at Each Reversal of the Work

The amount that the grinding wheel moves inward, before the feed is automatically disengaged, depends upon the distance between the end of shield *M* and the tooth of pawl *P*. Each time the table reverses, this pawl rotates ratchet *W* one or more teeth, and this feeding movement continues until shield *M* moves around and disengages the pawl, as previously mentioned. As a movement of one tooth represents a reduction in the diameter of the work of 0.00025 inch, the automatic feed can be set for grinding very close to a given size by varying the distance between the disengaging shield and the pawl. The feed can be set to give the full amount at each end of the stroke, or any part of the full amount at either end, by adjusting the regulating screws *F*. The feed on this particular machine can be varied from 0.00025 inch to 0.004 inch at each reversal of the table.

The automatic cross feed is a great advantage, especially when grinding a large number of duplicate parts, as it prevents grinding them too small and makes it unnecessary for the operator to be continually measuring the diameter of the work. The automatic feed is also desirable because it moves the wheel inward an unvarying amount at each reversal. This regularity of the feeding movement increases the *sizing power* of the grinding wheel. In other words, the wheel maintains its size for a longer period and the wear is more uniform. Of course, all grinding operations are accompanied by more or less wheel wear which has to be compensated for, although the amount of wear is surprisingly small when the wheel and work rotate at the proper speeds.

Use of Cooling Lubricant. — Another feature of the cylindrical grinder which should be referred to is the provision made for supplying cooling water to the wheel when grinding. At the point where the wheel is in contact with the work there is considerable heat generated; consequently, a cooling medium is very essential when grinding parts which revolve upon the centers, in order to maintain an even temperature. When water is not used, the part being ground tends to bend toward the wheel, owing to the higher degree of heat and expansion on the grinding side; in other words, its axis will be continually changing, and, obviously, inaccuracy will be the result. The apparatus for supplying the water consists of a small pump of the fan type which operates in a tank at the rear. The water is conveyed to the grinding wheel through a hose and pipe *O* (see Fig. 2), and plays upon that part of the work being ground at the contact point of the grinding wheel.

Example of Cylindrical Grinding. — As an example of grinding, to illustrate, in a general way, the adjustment and use of the machine previously described and other machines of similar construction, suppose a rather short shaft is to be ground cylindrical and to a diameter somewhere between 2.050 and 2.0495 inches, there being an allowable variation in size of 0.0005 inch. Before beginning to grind, a wheel should be selected that is suitable for the part to be ground. When grinding, the work must also be rotated at the proper speed, in order to minimize the wheel wear and secure a well-finished surface. The points to be considered when selecting the wheel and adjusting the work speed will be referred to later, in order to avoid confusion. We shall assume that a wheel of the proper grade and grain has been mounted on the spindle of the grinder and that a machine similar to the one shown in Fig. 2 is to be used. We shall also assume that the work has been rough-turned in a lathe to within about 0.010 inch of the required size.

The footstock *F* is first set the required distance from headstock *H* and then the work is placed between the centers with a driving dog attached to the headstock end, as illustrated in Fig. 4. The same center holes upon which the part was turned are also used when grinding, and they should be carefully cleaned before placing the shaft in the machine. The centers should also be oiled. When the shaft is in place, the reversing dogs *J* and J_1 are set to give the table the right length of stroke. The travel should be reversed when a small part of the wheel-face has passed the end of the piece being ground. If the stroke is too long, more time will be required for taking a cut than is necessary.

As the part is to be ground cylindrical or straight, the swivel table *A* should be set to the zero position. It should be remembered that the graduations are only intended to give an approximate setting, and when accuracy is required, it is necessary to test the work by using a micrometer or gage.

Setting the Automatic Feed. — When starting a cut and setting the automatic feed, the grinding wheel is moved in by hand until it is almost in contact with the work. The stroke of the table is then stopped, and, with this particular machine, pawl *P* is placed into engagement with the ratchet wheel. The latch *O* (see Fig. 3) is then raised and the head *N* moved around the periphery of the ratchet wheel until the point of shield *M* has just passed the tooth occupied by the pawl, so that the latter rests upon the shield.

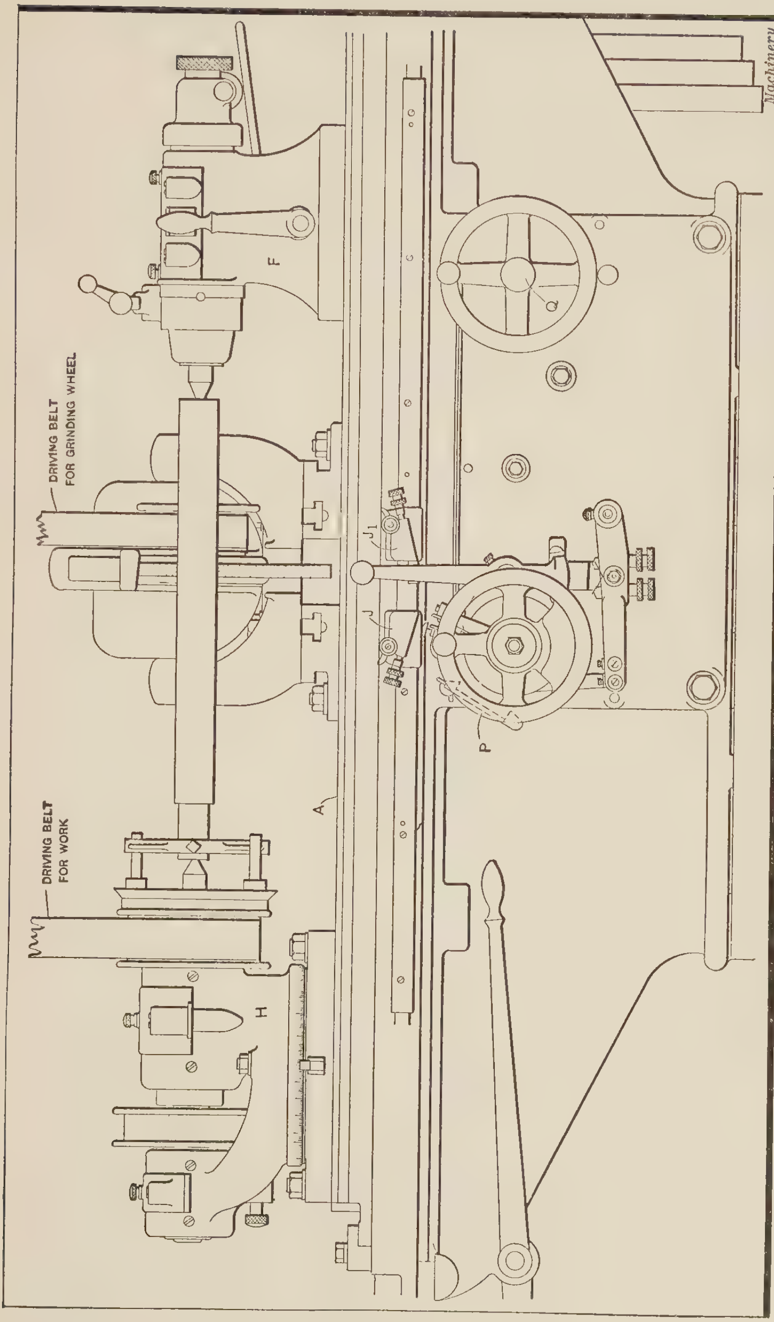


Fig. 4. Type of Machine illustrated in Fig. 2 Arranged for Grinding a Cylindrical Shaft (Steadyrests not in Position)

After the table stroke is again started, thumb-latch *T* is pressed until the grinding wheel begins to cut. When the surface is ground true, the table is stopped when the grinding wheel is at the footstock end, and the diameter of the part ground is measured with a micrometer. The thumb-latch *T* of the automatic feed is then pressed once for each quarter of a thousandth to be removed. To illustrate, suppose the diameter, after the surface has been trued, is 2.057 inches. Then there would be 0.007 inch stock to remove (2.057 − 2.050 = 0.007); hence, the latch would be pressed twenty-eight times, thus moving shield *M* far enough away from the feed pawl to allow the latter to continue feeding until 0.007 inch has been ground away.

When the feed has been set, the table traverse is again started and the grinding continued until the feed is disengaged. The wheel should then be stopped at the footstock end, as before, when the density of the sparks thrown off by the wheel have diminished somewhat and are about the same as for the final cut taken prior to the first measurement. If a suitable wheel has been used and the work rotated at the proper speed, the diameter should be very close to 2.050 inches, because, in this case, a comparatively small amount has been ground away, and, consequently, the wheel wear would be almost negligible. On the other hand, where it is necessary to remove considerable stock, the diameter of the work might be somewhat above the size for which the automatic feed was set, owing to the wear of the grinding wheel. After the amount of wheel wear for removing a given amount of stock is determined, the automatic feed can be set to compensate for this wear when grinding a duplicate part.

While the automatic feed will enable parts to be ground to a given diameter within close limits, this diameter should, of course, always be measured either with a micrometer or by the use of a fixed gage. As previously intimated, the accuracy of the automatic feed, for grinding to the diameter for which it is set, depends upon the amount the wheel wears, and the wheel wear, in turn, is governed by the "grade" of the wheel and the relation between the surface speed of the work and the grinding wheel speed.

Roughing and Finishing Cuts. — The exact method of procedure when grinding cylindrical parts often depends on the number of pieces to be ground and their shape. A single shaft having a diameter of, say, 2 inches and a length of 12 inches, could be ground by simply placing it between the centers with a dog attached and proceeding as described in the foregoing. On the other hand, if the shaft were long and flexible, it would have to be supported by work-rests or steadyrests to prevent deflection and vibration; work-rests are an advantage in most cases, regardless of the diameter or length of the part to be ground. A single shaft might also be finished by taking a number of light cuts which would be, practically, a succession of finishing cuts, whereas a number of pieces would be first "rough" ground and then finished.

The difference between roughing and finishing in the grinder is as follows: For roughing, a fast side traversing movement is used that is almost equal to the face width of the wheel, and comparatively deep cuts are taken, whereas, for finishing, the depth of cut and usually the side feed are reduced, in order to obtain a fine, smooth finish. The rotative speed of the work is also changed for finishing; in some shops the speed is increased, whereas, in others, it is diminished. This variation in practice is due principally to the use of different grades of grinding wheels for the same class of work.

The wear of a grinding wheel, as previously mentioned, depends very much on the surface speed of the work, the wear of a given wheel increasing as the work speed is increased; hence, assuming that a wheel of the right grain and grade is being used, the work speed for roughing should be so regulated that the wheel-face will be kept sharp and free cutting without excessive wear. In order to grind rapidly, it is the modern practice to use a coarse side feed of the wheel; that is, instead of feeding the wheel a distance equal to only $\frac{1}{8}$ or $\frac{1}{4}$ its width per revolution of the work, it is given a side feed that is only a little less than the full width of the wheel-face. This method of traversing the wheel is applied to the grinding of duplicate parts in connection with manufacturing operations, rather than to fine tool-room work. Comparatively wide wheels are also used in modern manufacturing machines, so that a surface can be ground rapidly.

Suppose the work is rotated fast enough to give a surface speed of 25 feet per minute and the fastest side feed is engaged in order to determine by trial what combination will give the best results. When the wheel is brought into contact with the work, if it leaves coarse, spiral feed lines (as shown at *A*, Fig. 5) having a greater pitch than the width of the wheel, the side feed should be reduced until the wheel does not leave any unground surface. On the contrary, if the fastest side feed only moves the wheel laterally a fraction of its full width (as indicated by the narrow feed lines at *B*), the work speed should doubtless be reduced until the side feed is nearly equal to the wheel width. Owing to the rapid side feed, the wheel will pass over the surface being ground in a comparatively short time, and by using a rather slow work speed, the wear of the wheel is minimized. This method of grinding is employed when using large machines which have sufficient driving power to enable such broad cuts to be taken and are rigid enough to prevent excessive vibration. When a small light grinder is employed, it is not feasible to use wide wheels and take such wide cuts, owing to the lack of rigidity and driving power. The depth of the cut, or the amount that the wheel feeds inward at each

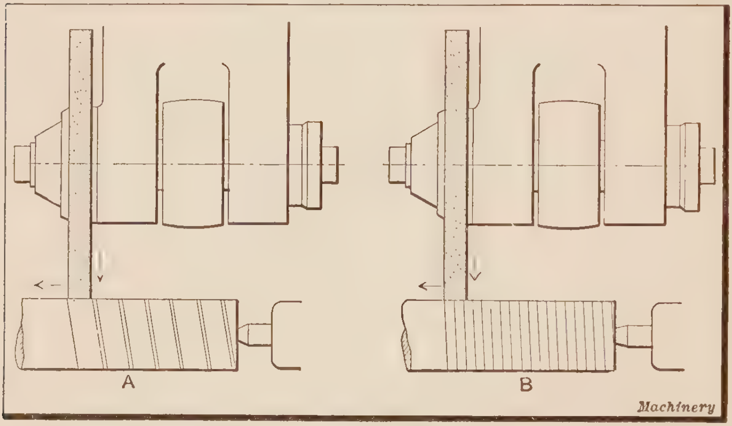


Fig. 5. (A) Wheel with Excessive Side Traverse or Feed. (B) Wheel Feeding Laterally a Fraction of its Width for Each Revolution of the Work

reversal, is also controlled by the power and rigidity of the machine used.

The grinding wheel should never be used unless it runs true and has an even bearing on the surface of the work. Different methods of truing grinding wheels are described in Chapter VIII.

Estimating Depth of Cut by Sparks. — The shower of sparks thrown off by the grinding wheel is a very convenient and sensitive indication of the depth of the cut, and, with a little practice, it is possible to gage the cut to within very close limits by this method. An interesting experiment was made to determine what the depth of a cut would be when the sparks were just visible. A hardened steel gage was ground very carefully, and, when taking the final cut, the work was traversed past the wheel until no sparks were visible. The exact diameter of the gage was then found by using a measuring machine, after which the gage was again placed in the grinder and the wheel was fed forward very slowly until sparks were just visible. The gage was then traversed past the wheel, as before, until all the sparks had disappeared. Then by again measuring the diameter, it was found that a reduction of 0.00001 inch had been made. One not experienced in grinding machine operation should become familiar with the relation between the shower of sparks thrown off by the wheel and the depth of the cut. It is well for the inexperienced operator to note the density of the sparks when cuts of a known depth are being taken. With a little practice, one can judge the depth of a cut by this method with considerable accuracy.

Different Methods of Cylindrical Grinding. — There are four general methods of applying the wheel to the work when grinding cylindrical parts; the first method, known as *traverse grinding*, was referred to in connection with Fig. 1 and is also illustrated by the diagrams shown at *A* and *B* in Fig. 6; the work or wheel is traversed by hand or power feed and the wheel is fed in automatically a certain distance at the end of every stroke.

The second method, shown at *C*, is known as the *fixed-wheel method*. By this method, instead of feeding the wheel in at each traverse, it is fed in to the correct depth determined by a previously set stop; two traverses are made over the work, one being a roughing cut and the other a finishing. Parts are also ground by leaving the wheel slide "fixed," that is, instead of feeding the wheel in on the work each time a new piece is put between the centers, the wheel slide is not adjusted until truing of the wheel has reduced its diameter, necessitating resetting.

The third method, shown at *D*, is known as the *step-in method* of grinding. By this method a comparatively wide face wheel, varying from 2 to 4 inches in width, is stepped-in along the work at intervals, the width of the wheel overlapping until the entire length to be ground has been covered. The wheel is fed in to within from 0.002 to 0.003 inch of the final diameter, and then two rapid traverses are made over the work to complete it.

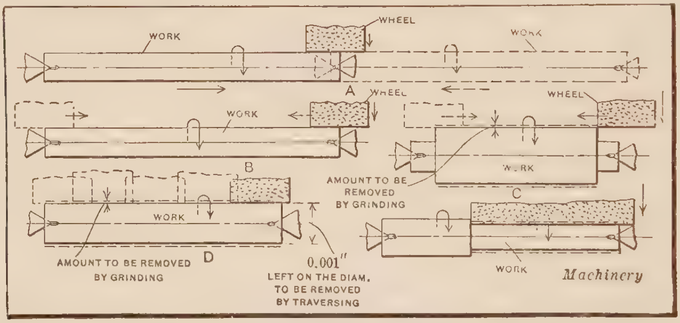

WHEEL
WORK
WORK
A
WHEEL
WHEEL
WORK
B
AMOUNT TO BE REMOVED BY GRINDING
WORK
C
WORK
AMOUNT TO BE REMOVED BY GRINDING
D
0.001"
LEFT ON THE DIAM. TO BE REMOVED BY TRAVERSING
WORK
Machinery

Fig. 6. Diagram illustrating Different Methods of Applying Wheel to Work for External Cylindrical Grinding

The fourth and last method is known as *straight-in* or *form grinding*. This term indicates that the wheel and work remain stationary, as far as lateral adjustment is concerned, and the wheel is fed directly in against the work without any traversing motion. This method of grinding can be used both for the grinding of straight plain surfaces and irregular-shaped form surfaces. Each of these four methods of grinding has its advantages and limitations.

Traverse Grinding. — Traverse grinding is recommended on long shafts, say over 2 feet in length, of comparatively small diameter; up to within the last few years this was the only recognized method of plain cylindrical grinding. When the work is short in proportion to its diameter, however, other methods of grinding, which will be described, often have certain advantages over the traversing method. The traversing method, in addition to being used very extensively for grinding such parts as engine piston-rods, spindles, shafts, etc., is used almost exclusively on grinding machines of light construction and on light accurate work. There are two methods of feeding the wheel in against the work for traverse grinding; one is to feed the wheel in from about 0.0005 to 0.001 inch for every traverse of the wheel past the work, or the work past the wheel (depending on the type of machine used), and the other is to make two traverses of the wheel or work for each feeding-in movement. In rough-grinding, the wheel is fed in a distance varying from 0.0015 to 0.003 inch at each forward stroke, the spring in the material being depended upon to provide for a light cut on the return stroke. For finishing, the wheel is generally fed in about 0.0005 inch at every traverse of the wheel past the work, or the work past the wheel, and usually from one to two traverses are made at the finish without any in-feeding of the wheel at all.

Fixed-wheel Method of Grinding. — The fixed-wheel method of grinding on many classes of work supersedes traverse grinding from a production standpoint; for example, short lengths of work (not shoulder shafts) such as bushings, etc., can be economically ground by this method. The practice is to start by feeding the wheel in and traversing over the work until the work has been ground to the final size; then the position of the wheel is fixed, that is, it remains stationary as far as in-feeding is concerned, and for the next piece the wheel is fed straight across the work, taking a heavy cut; then it returns with a light cut, finishing the work to the required diameter.

This method of grinding is hard, of course, on the corner of the wheel, and the general practice is to true the "feeding side" of the wheel to a slight angle. The extreme edge of the wheel is reduced about 0.030 inch in diameter and the face gradually tapered for about $\frac{1}{4}$ to $\frac{1}{2}$ inch. As following examples will show, this method of grinding is a highly productive one on classes of work for which it is adapted, but it could not be used with any degree of success on extremely long slender shafts because of the liability of chatter and springing of the work, even though it were rigidly supported by steadyrests. It also has a tendency to wear the wheel down rapidly, and difficulty is sometimes experienced in getting a wheel that will not clog or glaze and will still be hard enough to grind several pieces without retruing or resetting of the wheel slide. This method, however, is particularly adapted to the grinding of bronze and cast-iron bushings, and work of a similar character. As far as the allowance for grinding is concerned, less metal is left on the diameter of the work to be removed by the grinding wheel, when the fixed-wheel method of grinding is used, than when the regular traverse method is employed.

Step-in Method of Grinding. — The step-in method of grinding, as previously explained, consists in stepping the wheel in at intervals along the surface of the work to within about 0.001 to 0.003 inch of the finished size, and then making several rapid traverses — generally about two. This method can be used advantageously on comparatively long shafts that are either hard or soft when ground, but is of very little advantage on shoulder shafts or extremely long slender work. Some manufacturers are using this method for grinding parts that others are producing by the straight-in or form method. The step-in method can be used on comparatively light grinding machines that would not be suitable for form grinding; furthermore, wheels of comparatively narrow face as compared with those used for form grinding can be used. Generally, for step-in grinding, the wheel used is about 2½ to 3 inches width of face, and about ¼ to ½ inch overlapping of the wheel is allowed for successive wheel positions along the work. The comparative production figures of work ground by the regular traverse method and that ground by stepping-in along the work show that the step-in method, from a production standpoint, is superior to the traverse method for certain classes of work. The illustrations which follow show several good examples of step-in grinding. These will serve to point out the classes of work on which this type of grinding can be used to advantage.

Straight-in or Form Grinding. — Form or straight-in grinding is a comparatively recent development of the grinding art. To accomplish this work has necessitated the entire re-designing of grinding machines; considerable investigation into the subject of grinding wheels being also necessary. This subject is at the present time such an extensive one that it has been treated separately in Chapter II. Form grinding has its limitations as well as its advantages. On work over 10 inches in length, it cannot be used to advantage, and in fact on work of small diameter up to about 6 inches in length, it shows very little advantage, as far as production is concerned, over traverse grinding. In connection with the chapter on form grinding many examples are given that clearly show the advantages of this modern method of finishing machine parts.

Allowances for External Cylindrical Grinding. — The amount of metal to leave on the diameter of a piece for finish by grinding is governed by several conditions, among which might be mentioned: First, finish secured in lathe-turning operation; second, condition of work when being ground, whether hard or soft; third, shape of work, whether in the form of a solid shaft or in the form of a thin wall bushing; fourth, when casehardened, the depth to which the casehardening scale penetrates; fifth, length of portion ground in proportion to its diameter; sixth, shape of work, whether plain cylindrical or having a number of shoulders.

The nature of the lathe-turning operation preceding grinding has probably more to do with governing the allowance on the diameter for grinding than any other one factor. If the work is turned too close to the finish size before grinding, it is evident that less material will have to be removed by the grinding wheel; but light cuts and fine feeds in turning are not always the most economical way of manufacturing any particular part. On the other hand, if too large an allowance is left for grinding, this also is not economical because a large amount of stock could be more economically removed by rough-turning.

In general manufacturing practice, the part is rough-turned in the lathe, using a round-nose tool at a very coarse feed, of say $\frac{1}{16}$ to $\frac{1}{10}$ inch per revolution of the work, thus leaving a rough ridged surface. By this method of turning, quite a large limit is allowed because of the coarse feed used, which increases the difficulty of measuring the smallest diameter turned, the measuring tool taking the reading on the tops of the ridges.

The amount of stock that can be removed economically by grinding also depends, to a certain extent, upon the size and power of the grinding machine used. Where a very powerful and rigid grinding machine is used, carrying a comparatively wide-face wheel, considerable stock can be removed by the grinding machine. For ordinary commercial grinding on shaft work, the work is generally reduced in the lathe to within somewhere between $\frac{1}{64}$ and $\frac{3}{64}$ inch of the required diameter. When the diameter has been rough-turned to these dimensions, it is much more economical to remove the stock by grinding than by taking a light finishing cut in the lathe, provided, of course, that a grinding machine of sufficient power is available. Table I gives the allowance to be left on the diameters for grinding average work, but does not take into consideration special cases such as an extremely rough finish before grinding, hardened thin wall bushings that are liable to warp out of shape to a greater or less extent, or long shaft work that has been considerably sprung out of shape in hardening.

Table I. Allowances for External Cylindrical Grinding

Diameter of Work in Inches	Length of Work in Inches									
	4	6	8	10	14	18	24	36	48	60
¼	0.008	0.010	....	....	....	....	....	....	....	....
⅜	0.008	0.010	0.012	0.013	....	....	....	....	....	....
½	0.009	0.011	0.012	0.013	0.015	0.016	....	....	....	....
¾	0.009	0.011	0.013	0.014	0.016	0.017	0.018	....	....	....
1	0.010	0.012	0.013	0.014	0.016	0.018	0.019	....	....	....
1¼	0.011	0.012	0.014	0.015	0.017	0.018	0.019	0.022	....	....
1½	0.011	0.013	0.014	0.016	0.017	0.018	0.019	0.023	....	....
1¾	0.012	0.013	0.015	0.016	0.018	0.019	0.020	0.023	0.026	....
2	0.013	0.014	0.016	0.017	0.018	0.019	0.021	0.024	0.027	....
2½	0.015	0.016	0.017	0.018	0.019	0.020	0.022	0.025	0.028	0.032
3	0.016	0.017	0.018	0.019	0.020	0.022	0.024	0.027	0.030	0.034
3½	0.017	0.018	0.019	0.020	0.022	0.023	0.025	0.028	0.032	0.035
4	0.018	0.019	0.020	0.021	0.023	0.025	0.027	0.030	0.033	0.037
5	0.019	0.021	0.022	0.023	0.025	0.027	0.029	0.032	0.036	0.039
6	0.021	0.023	0.024	0.025	0.027	0.029	0.031	0.035	0.039	0.043
7	0.023	0.025	0.026	0.027	0.029	0.031	0.033	0.037	0.041	0.044
8	0.025	0.027	0.028	0.029	0.031	0.033	0.035	0.039	0.043	0.045
9	0.027	0.028	0.029	0.030	0.032	0.034	0.036	0.040	0.044	0.045
10	0.028	0.030	0.031	0.032	0.033	0.035	0.037	0.042	0.045	0.045
11	0.030	0.031	0.032	0.033	0.035	0.036	0.038	0.043	0.045	0.045
12	0.031	0.032	0.033	0.034	0.036	0.038	0.040	0.045	0.045	0.045

Of course, long hardened shaft work, as a rule, requires straightening previous to grinding, but it is difficult to anticipate what will happen when the hardened part is ground. The figures given in this table represent a fair average allowance used in a number of shops where parts to be ground are turned to specified sizes which are regulated by the use of snap gages.

There are two distinct methods recommended for roughing out the work previous to grinding: One is to carefully turn the work to within from 0.010 to 0.015 inch of the finished size, and then finish by grinding; the other is to rough out the work quickly, taking light cuts (when the work is slender) with comparatively coarse feeds and high work speeds, leaving about $\frac{1}{32}$ inch to remove by grinding. As the tool "cuts a thread" or leaves a ridged surface on the work, only the high points have to be removed by the grinding wheel over and above the amount left for grinding when the work is turned smooth. There are advantages in both methods, depending on the class of work being machined. Where the work is large in diameter in proportion to its length and will stand heavy lathe cuts, the latter method can be used to advantage; but where the work is light or small in diameter in proportion to its length, the first mentioned practice is generally followed.

The grinding allowance for parts which have to be hardened naturally depends, to some extent, upon the shape of the part and the liability of distortion due to the hardening process. When parts are to be carburized or casehardened, it is important to finish them rather smoothly prior to hardening, so that the depth of the hardened case will be fairly uniform over the entire surface. The allowance should also be small enough so that the hard case will not be removed entirely by grinding or be reduced excessively. For some classes of work it is practicable to grind bar stock from the rough without any preliminary turning operation, although most work is first turned. When using a light grinder, the allowance for grinding must be comparatively small and is governed, more or less, in any case, by the size and character of the work as well as by the power and stock-removing capacity of the grinding machine.

Preparation of Work for Grinding. — Hardened parts that are to be ground may be so bent or distorted as to require straightening, but when this is done they are liable to resume the crooked form after considerable time has been spent in grinding. As a rule, this results from lack of care in preparing the steel previous to the machining operations. Steel, as it comes from the mill or forging machine, is likely to contain hidden strains that can only be released by reheating or annealing. If the annealing operation is carefully handled, it is possible to remove these strains and put the steel in such a condition that warping in hardening is reduced to a minimum.

Before a bar of tool steel, that is subsequently to be hardened, is turned preparatory to grinding, it should be carefully centered and straightened (if necessary) prior to turning, especially if the rough bar is not much larger in diameter than the size required. The bar in its roughened condition is decarbonized on the surface, as well as for a slight distance below it, and this material must be removed in order to make the piece harden evenly. It is preferable to straighten a bar after it has been heated; it can then be roughed out in the lathe and carefully annealed after the roughing cut has been taken. If the bar should be crooked after the second annealing operation, it should be again straightened while hot and another cut taken. As a rule, this leaves it in a satisfactory condition for grinding.

In grinding shoulder shafts where the grinding machine is not provided with locating stops, it is generally advisable to "neck" the shaft at the shoulder or form a recess previous to grinding, if a sharp corner is required on the work; then the operator does not need to be as careful in bringing his wheel in to the shoulder as he would if no clearance space were provided. When shoulder shafts are to be hardened previous to grinding, however, it is advisable, where possible, to have the corner rounded, leaving a liberal fillet to prevent warping and water cracks developing. Another point that should be observed in the grinding of shoulder shafts is to have the center holes all of the same depth, in order that the stop for governing the location of the shoulders need not be changed for each shaft. It is necessary to give particular care to the centers in the work, especially when a large number of duplicate pieces are to be produced.

When the shaft to be ground is provided with keyways, the best procedure is to first turn the shaft to the roughing size, then cut the necessary keyways, and do the grinding last. Work cannot be finished satisfactorily in the lathe with a keyway cut in it, and if the grinding is done after the keyway is cut, all objectionable burrs are removed and the work is finished without filing. In work that is hardened, the centers should be cleaned out and care taken to see that no burrs have been formed, or that they have been otherwise deformed. It is impossible to get true cylindrical work on a poor center. A good lubricant for grinding machine centers is a mixture of powdered red lead (oxide of lead) and lard oil. When using this lubricant, if the lead dries out, the centers do not cut but simply take on a high polish.

Width of Grinding Wheel Face. — The width of face to use for a grinding wheel is governed largely by the work to be ground and to some extent by the machine to be used. In the first grinding machines, which were built for cylindrical grinding operations, narrow face wheels were used because the grinding machine was designed for finishing parts only, and, consequently, was lightly constructed. Wide face wheels could not be used on the machine because of the liability of chatter from vibration, and wheels much wider than $\frac{1}{2}$ inch were uncommon. In fact, a $\frac{1}{2}$-inch wheel was at first the standard width for most work.

Following closely on the improvements made in the design of grinding machines, the width of wheel-face was gradually increased for cylindrical grinding, until at the present time wheels as wide as 12 inches are used for some grinding operations. For traverse grinding, there are certain conditions that govern the width of the wheel. Referring to diagrams *A* and *B* in Fig. 7, a 1-inch face wheel is shown taking a roughing and finishing cut, respectively. When rough-grinding, a traverse feed is used that will enable the bulk of the material to be quickly removed. In theory, this traverse feed is supposed to be about equal to the width of the wheel, that is, the wheel would be advanced an amount equal to its width at each revolution of the work. In practice, however, this is very seldom used and a feed of from two-thirds to nearly the full width of the wheel per revolution of the work has been found to give the best results. In finish-grinding, the traverse feed of the wheel is somewhat reduced and is generally about one-third to one-quarter of the roughing feed.

Two of the chief requirements, when grinding, are production and accuracy, either of which may be considered the more important. Usually, production is the factor that is most sought; consequently, anything that tends to increase production is of value. One of the factors that assists in increasing production is increasing the width of the wheel-face. This, as shown at *C* in Fig. 7, enables greater traverse feeds to be taken, and where the machine is of sufficient power and rigidity, the wide face wheel is capable of greatly increasing production over a narrower face wheel. In other words, a greater number of pieces could be

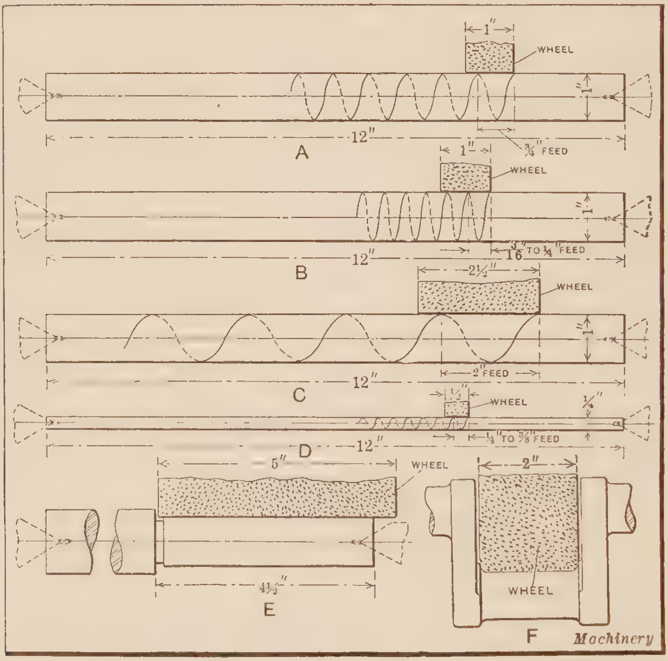


Fig. 7. Illustrations showing Conditions which govern Width of Grinding Wheels for External Cylindrical Grinding

turned out by the wheel shown at *C* than by that shown at *A* because of the possibility of increasing the traverse feed per revolution of the work. The most advanced practice, therefore, is to use a wide face wheel varying in width from about 1½ to 4 inches (for traverse grinding) and a comparatively coarse feed and slow work speed. In this way, the excess material on the diameter of the work can be removed most economically. Of course, in using a wide face wheel, it is necessary that the work be properly supported, and for this reason a liberal use of back-rests is advisable. In many cases, the greater the number of back-rests used, the greater will be the accuracy and production.

There are cases where the advantage of a wide face wheel is questionable. Take, for instance, a small slender shaft ¼ inch diameter and 12 inches long (see *D*, Fig. 2) which has been hardened. On hardened work a harder bond wheel is used than for soft work, and, consequently, there is a slightly greater pressure on the work when grinding it. For this reason it is sometimes advisable to reduce the width of the face of the wheel in order to reduce the wheel pressure. The practice with some manufacturers is to use an elastic wheel about ½ inch wide for both roughing and finishing cuts on work of this class, a wheel of softer bond being used for roughing than for finishing. The work must also be rigidly supported by back-rests, and light cuts with coarse traverse feeds and high work speeds are employed. There are cases, however, when a slender shaft can be ground with a comparatively wide face wheel, but this is recommended more for the grinding of soft work than for hardened work. Practice differs to some extent in the grinding of small slender shafts, depending on the condition of the work and the finish desired. On machine tool work, where a shaft is to be held to close limits, great care is exercised both in roughing and finishing, in order to get the desired results.

In "straight-in" grinding still another condition is presented which governs the width of the face of the wheel, as shown at *E* in Fig. 7. In this case, the wheel must be of a width slightly greater than the length of the portion to be ground, because it is fed straight in on the work without any lateral traverse. The usual practice is to have the wheel anywhere from $\frac{1}{4}$ to 1 inch wider than that portion of the work covered by it.

In grinding the pins of crankshafts, by the method shown at *F*, the width of face of the wheel is governed by the distance between the webs of the crank. In this case, the wheel has to be fairly accurate as regards width, and usually is slightly less in width than the distance between the webs; the webs for this design of crankshaft are finished, previous to grinding, in a lathe. There are, of course, other conditions met with in cylindrical grinding that call for specified widths of wheel-faces, but those given in the foregoing cover general practice.

Grinding Wheel and Work Speeds. — The peripheral or surface speed of a grinding wheel is usually somewhere between 5500 and 6000 feet per minute; speeds between 5000 and 6500 feet per minute are commonly employed, and, in some cases, wheels of hard bond are operated at speeds as high as 8000 feet per minute, although such high speeds are not recommended for general work. Grinding wheels made from corundum, alundum, aloxite, or other aluminous abrasives are generally operated at about 6000 feet per minute, whereas wheels made from carborundum, crystolon, carbolite, or wheels belonging to the carbide of silicon group are usually operated at about 5500 feet per minute.

As the wheel diminishes in size, it appears to get softer, even though the peripheral speed remains constant. This increase in wear is due to the fact that the abrasive grains are in contact with the work oftener as the size is diminished, owing to the increased number of revolutions necessary for maintaining the same surface speed. Table II gives the speeds of grinding wheels of various diameters in revolutions per minute for obtaining peripheral or surface speeds ranging from 4000 to 8000 feet per minute.

A wheel which is perfectly adapted to grinding a certain kind of material will not work satisfactorily if the relative surface speeds of the wheel and work are not approximately correct. The work speed affects the wear of the wheel, which, when excessive, also affects the finish of the surface being ground. The amount of stock that the wheel removes for a given amount of wear can be increased or diminished by varying the work speed, the wheel wear being excessive when the speed is too high. This close relation between the work speed and the wheel wear makes it possible to use a wheel which is somewhat harder than it should be for a given piece of work, by increasing the work speed, with the result that the grit is dislodged more easily, and, consequently, does not remain long enough to cause glazing, which would otherwise take place; this practice, however, is not to be recommended unless it is not feasible to secure a wheel of the proper grade.

Table II. Grinding Wheel Speeds

Diameter of Wheel in Inches	Surface Speed of Grinding Wheel in Feet per Minute								
	4000	4500	5000	5500	6000	6500	7000	7500	8000
	R.P.M. of Grinding Wheel								
4	3820	4297	4775	5252	5730	6207	6684	7162	7639
5	3056	3438	3820	4202	4584	4966	5348	5730	6112
6	2546	2865	3183	3501	3820	4138	4456	4775	5093
7	2183	2455	2728	3001	3274	3547	3820	4092	4365
8	1910	2148	2387	2626	2865	3103	3342	3581	3820
10	1528	1719	1910	2101	2292	2483	2674	2865	3056
12	1273	1432	1592	1751	1910	2069	2228	2387	2546
14	1091	1227	1364	1500	1637	1773	1910	2046	2183
16	955	1074	1194	1313	1432	1551	1671	1790	1910
18	849	955	1061	1167	1273	1379	1485	1592	1698
20	764	859	955	1050	1146	1241	1337	1432	1528
22	694	781	868	955	1042	1128	1215	1302	1389
24	637	716	796	875	955	1034	1114	1194	1273
26	587	661	734	808	881	955	1028	1101	1175
28	546	614	683	751	819	887	955	1022	1091
30	509	573	637	701	764	827	891	955	1019
32	477	537	597	656	716	775	835	895	955
34	449	505	561	617	674	730	786	842	898
36	424	477	531	584	637	690	743	796	849

As there are a number of factors, such as kind of material, finish desired, etc., which govern the proper work speed, it is impracticable to say just what this speed should be unless the conditions are known, and usually it is advisable to experiment somewhat when beginning to grind a new class of work, in order to determine the correct speed. A surface speed of twenty-five feet per minute might be correct for grinding a certain piece of steel, and not correct for another steel part having a different carbon content. The finish of a ground surface, as previously stated, is also affected by the work speed. It is possible to grind a very rough or smooth surface by simply varying the speed, depth of cut, and side feed of wheel. The best method of ascertaining the proper speed for a given piece of work, and, incidentally, of determining the best wheel to use, is by experimenting until the desired results are obtained. This does not necessarily mean that whenever a new piece of work is to be ground considerable time must be wasted, as the speed adjustments are easily made, and besides, experience will soon teach what combinations of speed will give the best results.

As is well known by those who have had experience in cylindrical grinding, it is difficult to lay down rules for determining the proper grade and grain of wheel, work speeds, and wheel speeds, because so many factors must be considered. As to the changes of speed made for the roughing and finishing cuts, some advise a reduction of speed for finishing, and others an increase in speed. This difference in the practice of various manufacturers can be accounted for by the fact that wheels of different grades are often used for grinding the same kind of material and the grinding machines used also differ as to size and rigidity of design. In some shops, comparatively coarse wheels of fairly soft bond are employed, while in others, the wheels are harder and more compact. In the case of the coarser, and, in many cases, softer wheels, when the speed for roughing is regulated so as to keep the wheel-face sharp, it leaves a rather rough surface on the work. After rough-grinding, the wheel-face is trued by traversing a rather dull diamond tool slowly across it, using the slowest table traverse. In this way the wheel-face is not only trued but is made smooth; then the work speed is reduced for finishing with the same wheel, in order to secure a finish that could not be obtained with a higher speed. On the other hand, if a finer and more compact wheel were used, the speed should be increased considerably for the light finishing cut.

Thus it will be seen that there are two methods of rough- and finish-grinding cylindrical work, one being to increase the work speed for finishing and decrease the traverse feed, and the other, to decrease the work speed as well as the traverse feed. Both methods are used to advantage in grinding practice and the one to be employed may depend upon several conditions. Suppose a comparatively soft free-cutting wheel is used. For rough-grinding, the work speed would usually be about 25 feet per minute, and if this same wheel were used for finish-grinding, it would be necessary to reduce the work speed about 20 or 25 per cent to get the desired finish. If a harder and more compact wheel were used for finishing, the speed would be increased over that used for roughing.

In modern grinding practice, when rough-grinding, it is generally advisable to use a fairly coarse wheel of a soft enough grade to remain "sharp" and cut freely, and a comparatively slow work speed in conjunction with a coarse side feed of the wheel or work. This method can be used to the best advantage on machines that are heavily constructed and provided with sufficient driving power to enable these broad cuts to be taken without excessive vibration. With a light grinding machine, however, this coarse feed is not advisable, owing to the lack of rigidity and the low driving power, so that the question as to whether a high or low work speed for finishing is preferable, depends, in most cases, upon the wheel used and to a certain extent upon the machine that carries it, as well as the nature of the grinding operation. As a general rule, the harder the bond and finer the grain of the wheel used, the higher should be the work speed.

A general idea of the work speeds ordinarily used for different grinding operations may be obtained from the specific examples which will be referred to later. The surface speeds for parts being ground may be divided into three general groups, each subject to considerable variation owing to different conditions. For heavy grinding operations, the speeds may vary from 15 to 25 feet per minute, with a side traverse of from two-thirds to nearly the full width of the wheel per revolution of the work. In extreme cases, speeds as low as 5 feet per minute have been employed. When the speed is, say, 25 feet per minute, the grinding is ordinarily done with a broad free-cutting wheel of comparatively soft bond, and the work speed is reduced about 20 or 25 per cent, and the same wheel is used for the finishing cut. Prior to finishing, however, it is trued by slowly traversing a rather dull diamond across the face, as previously mentioned, thus forming a temporary finishing surface upon a coarse wheel. The rate of traverse is commonly reduced somewhat for the finishing cut.

When using wheels of somewhat harder bond, the speeds for roughing often range from 25 to 30 feet per minute, and, for finishing, from 35 to 40 feet per minute, the rate of traverse varying from nearly two-thirds to full width of the wheel, except for finishing, when it is usually reduced an amount depending upon the finish or polish desired. In this case, the harder bond makes it possible to operate the work at a higher speed, although the grinding operation may not be as efficient as when grinding by the first method referred to. For some classes of grinding, the work speeds vary from 60 to 90 feet, and wheels of comparatively hard bond and fine grain are used. For instance, the speeds may vary from 40 to 60 feet for roughing and from 60 to 90 feet for finishing, with a side traverse of from one-fourth to one-half the wheel width per revolution of the work. These hard bonded wheels are commonly used in connection with toolroom grinding and similar operations, especially when grinding comparatively small work. The wheels used are generally quite narrow as compared with the wheels usually employed when grinding by the slower work-speed method first referred to. For average work, the Brown & Sharpe Mfg. Co. recommends a surface speed for roughing varying from 25 to 65 feet, with an increase of from 10 to 20 feet per minute for finishing. For roughing cast iron, some authorities recommend a speed of about 40 feet per minute, and, for finishing, a speed of 50 feet per minute.

From the foregoing, it will be seen that the finishing speed must be varied in accordance with the kind of wheel used for grinding. When choosing a grinding wheel, if one too hard for the work is selected with the idea of reducing the wheel wear,

Table III. Work Speeds for Rough- and Finish-grinding Various Materials

Work speeds based on 6000 feet surface speed for Alundum, Aloxite, and Corundum Wheels, and 5500 feet for Carbolite, Carborundum, and Crystolon Wheels

Material	Abrasive	Bonding Process	Grain	Grade	Surface Speed of Work in Feet per Minute	
					Roughing	Finishing
Aluminum (cast)	Carbolite, Carborundum, or Crystolon	Elastic	36 to 40 36 to 40 36 to 40	2 E to $2\frac{1}{2}$ E 2 4	60 to 70	60 to 70
Brass or bronze (cast)	Corundum, Carborundum, or Crystolon	Vitrified	24 to 30 24 to 30 24 to 30	M to N L to M P	50 to 60	60 to 70
Iron (cast)	Carbolite, Carborundum, or Crystolon	Vitrified	40 to 46 40 to 46 40 to 46	K to M L to N L to M	50 to 55	50 to 55
Alloy steel, heat-treated	No. 38 Alundum No. 58 Corundum Aloxite	Vitrified	24 Comb. 24 Comb. 40	L L J	20 to 25	30 to 40
Steel 0.20 to 0.50 per cent carbon (soft)	No. 38 Alundum No. 58 Corundum Aloxite	Vitrified	24 to 36 Comb. 24 to 36 Comb. 36	L to M L to M M to O	25 to 30	40 to 45
Steel 0.20 to 0.50 per cent carbon (hardened)	Alundum, Corundum, or Aloxite	Vitrified	46 46 36	K K P	30 to 35	50 to 55

the corresponding reduction in the output may much more than offset the increased expense incurred by using a softer and more rapidly wearing wheel, because the latter cuts more rapidly. The wheel wear, however, should be considered, and, as it is dependent upon the work speed, the vibration of the work, and depth of cut, these should receive careful attention.

The nature of the material being ground also has a bearing upon the speed of the work, and, assuming that a satisfactory wheel for the work has been selected, the surface speed for the work can then be more easily determined. The work speeds for different materials given in Table III are taken from general practice, and do not cover special conditions or take into consideration the diameter of the work, which also is a deciding factor in the selection of the proper work speed to use. Table IV gives the speed of the work in revolutions per minute for obtaining various surface speeds.

Depth of Cut. — The depth of cut per traverse of the wheel or work varies from 0.0005 to 0.003 inch. For roughing out, the depth of cut (on the radius of the work) varies from 0.0015 to 0.003 inch, and for finishing, from 0.0005 to 0.001 inch, with a very light cut on the final traverse. The depth of cut bears an inverse ratio to the traverse speed and can be increased without any marked change of results, provided the side traverse is correspondingly decreased.

When certain combinations of speed, feed, depth of cut, etc., have been found correct for a certain kind and size of material, it is advisable to record this information for future reference, for while such data may not always be applicable, owing to a difference in the nature or form of the material, it will, in many instances, enable one to determine the most efficient speed and feed conditions in a comparatively short time.

Methods of Preventing Chatter. — Chattering is generally attributed chiefly to vibration. It was not recognized, at first, that chatter marks were caused by the vibration of the work itself, but the fault was laid to vibration of the machine and the foundation upon which it was placed. Considerable time and money was spent on foundations before the true cause of chatter

Table IV. Work Speeds for Cylindrical Grinding

Diameter of Work in Inches	Surface Speed of Work in Feet per Minute																	
	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	90	100
	R.P.M. of Work																	
¼	76.4	152.8	229.0	305.0	382.0	458.0	535.0	611.0	688.0	764.0	851.0	917.0	994.0	1070.0	1147.0	1222.0	1376.0	1528.0
⅜	50.9	101.8	153.0	204.0	255.0	306.0	357.0	408.0	458.0	509.0	560.0	611.0	662.0	713.0	764.0	815.0	916.0	1018.0
½	38.2	76.4	114.0	153.0	191.0	229.0	268.0	306.0	344.0	382.0	420.0	459.0	497.0	535.0	573.0	611.0	688.0	764.0
⅝	30.6	61.2	92.0	122.0	153.0	184.0	214.0	245.0	276.0	306.0	337.0	367.0	398.0	428.0	459.0	489.0	552.0	612.0
¾	25.4	50.8	76.5	101.0	127.0	153.0	178.0	203.0	229.0	254.0	279.0	306.0	330.0	357.0	381.0	408.0	458.0	508.0
⅞	21.9	43.8	65.5	87.5	109.0	131.0	153.0	175.0	196.0	219.0	241.0	262.0	285.0	306.0	329.0	349.0	392.0	438.0
1	19.1	38.2	57.5	76.5	95.5	115.0	134.0	153.0	172.0	191.0	210.0	229.0	258.0	267.0	287.0	306.0	344.0	382.0
1⅛	17.0	34.0	51.0	68.0	85.0	102.0	119.0	136.0	153.0	170.0	187.0	204.0	221.0	238.0	255.0	272.0	306.0	340.0
1¼	15.3	30.6	45.9	61.5	76.3	91.8	107.0	123.0	137.0	153.0	168.0	183.0	199.0	214.0	230.0	245.0	274.0	306.0
1½	12.7	25.4	38.1	51.0	63.7	76.3	89.2	102.0	115.0	127.0	140.0	153.0	165.0	178.0	191.0	204.0	230.0	254.0
1¾	10.9	21.8	32.7	43.6	54.5	65.5	76.4	87.3	98.2	109.0	120.0	131.0	142.0	153.0	164.0	175.0	196.0	218.0
2	9.5	19.1	28.6	38.2	47.8	57.3	66.9	76.4	86.0	95.5	105.0	115.0	124.0	134.0	143.0	153.0	172.0	191.0
2¼	8.5	17.0	25.5	34.0	42.2	51.0	59.4	68.0	76.2	85.5	93.5	102.0	111.0	119.0	128.0	136.0	153.0	170.0
2½	7.6	15.3	22.9	30.6	38.2	45.8	53.5	61.2	68.8	76.3	84.2	91.7	99.5	107.0	114.0	122.0	138.0	153.0
2¾	6.9	13.9	20.8	27.8	37.4	41.7	48.6	55.6	62.5	69.5	76.5	83.4	90.4	97.2	104.0	111.0	125.0	139.0
3	6.3	12.7	19.1	25.5	31.8	38.2	44.6	51.0	57.3	63.7	69.9	76.4	82.6	89.1	95.3	102.0	114.0	127.0
3½	5.4	10.9	16.3	21.8	27.3	32.7	38.2	43.6	49.1	54.5	60.0	65.5	70.8	76.4	81.8	87.4	98.1	109.0
4	4.8	9.5	14.3	19.1	23.9	28.7	33.4	38.2	43.0	47.8	52.6	57.3	62.1	66.9	71.7	76.4	86.0	95.6
4½	4.2	8.5	12.7	17.0	21.2	25.4	29.6	34.0	38.2	42.4	46.6	51.0	55.1	59.4	63.6	67.9	76.3	84.8
5	3.8	7.6	11.4	15.8	19.1	22.9	26.7	30.6	34.4	38.2	42.0	45.9	49.7	53.5	57.3	61.1	68.8	76.4
5½	3.4	6.9	10.4	13.9	17.4	20.8	24.3	27.8	31.3	34.4	38.2	41.7	45.1	48.6	52.0	55.6	62.5	69.4
6	3.2	6.3	9.5	12.7	15.9	19.1	22.3	25.5	28.7	31.8	35.0	38.2	41.3	44.6	47.7	51.0	57.2	63.6
7	2.7	5.4	8.2	10.9	13.6	16.4	19.1	21.8	24.6	27.3	30.0	32.7	35.5	38.2	41.0	43.7	49.1	54.6
8	2.4	4.8	7.6	9.5	11.9	14.3	16.7	19.1	21.1	23.9	26.3	28.7	31.0	33.4	35.9	38.2	43.0	47.8
10	1.9	3.8	5.7	7.6	9.5	11.4	13.3	15.3	17.2	19.1	21.0	22.9	24.8	26.7	28.6	30.5	34.4	38.2
12	1.6	3.2	4.7	6.3	7.9	9.5	11.1	12.7	14.3	15.9	17.5	19.1	20.6	22.3	23.8	25.5	28.6	31.8

was ascertained. It is now generally recognized that practically all work that is ground will vibrate to a greater or less extent under the cut of the wheel, regardless of the machine in which it is ground. Chatter is usually caused by the work not being properly supported and by the use of incorrect work speeds. By selecting the correct work speed and properly supporting the work, it is possible to grind cylindrical parts round and smooth and produce accurate surfaces.

Chatter in the work is sometimes attributed to imperfect gearing in the machine, where the machine is of the gear-driven type. As a rule, however, it will be found that the gearing is correct and the marks are caused by the vibration of the work. It is probable, in some cases, that the driving dog sets up vibration, owing to the fact that there is torsion in the dog when a heavy cut is taken and when the work is not properly supported. Chatter marks usually take the form of small flats that appear on the surface of the work, and it is sometimes possible to locate the trouble from the appearance of these flats. They also assume, in some cases, a spiral form of coarse pitch, which generally indicates that the wheel is untrue or not of homogeneous structure. When they are of a fine pitch in spiral form, the cause is generally vibration of the wheel-spindle, which may be either too weak or loose in its bearings. Driving belts that are of unequal thickness may vibrate the wheel-spindle to such an extent as to cause chatter of the work. Another method to obviate chatter on large work is to provide the work with larger center holes so as to have as large a support as practicable on the centers. Chattering can sometimes be avoided by giving particular attention to the relation of the wheel and the work speed, by having these speeds so adjusted that the wheel will not have a tendency to glaze, but will be free-cutting at all times.

Chatter marks are likely to develop in the grinding of crankshafts, or other work that is of irregular shape, or eccentric at various portions along its length. This is due to the eccentricity of the revolving mass throwing the work out of balance and causing vibration. One way to avoid this is to reduce the speed of the work, but the most satisfactory way is to balance the work properly so as to reduce the vibration to a minimum. Assuming that the grinding machine is in perfect running condition, and that the wheel is perfectly balanced and properly dressed, if chatter marks develop it is a sure indication that the work is improperly supported.

Steadyrests for Grinding. — Practically all parts that are ground on centers should be supported by suitable steadyrests or back-rests, as their use will not only obviate chattering, when properly applied, but permit taking deeper cuts with coarser feeds and also increase the "sizing power" of the wheel. When grinding long and slender parts, such supports are indispensable, and, even for work which is short and rigid, steadyrests are desirable to prevent vibration, which increases wheel wear and affects the quality of the ground surface. These supports are fastened to the table of the machine and are equipped with shoes of hard wood or metal which bear against the piece being ground. The number of steadyrests used depends on the form and diameter of the work. According to a commonly accepted rule, the distance between each steadyrest should be from six to ten times the diameter of the part being ground. Some recommend the use of as many rests as can conveniently be fixed in position.

Steadyrests are made in several different styles, and they may be divided into two general classes which differ in that one type is rigid and the other flexible. The rigid type gives a positive unyielding support, whereas the flexible steadyrest, as the name implies, can yield more or less, the supporting shoe being held against the work by springs. Most rigid steadyrests must be readjusted by hand as the diameter of the work is reduced by grinding, whereas the shoes of the flexible type adjust themselves automatically after being properly set. Then there is another form of steadyrest which has spring tension, but can be made rigid when desirable, and still another type is so designed that the supporting shoes are adjusted automatically, but the support is unyielding.

There is a difference of opinion among grinding machine operators and manufacturers regarding the relative merits of the rigid steadyrest and the flexible or spring type. Some advise the use of spring steadyrests for supporting light slender work, and the fixed or rigid form when grinding heavy stiff parts, whereas others advocate the use of rigid steadyrests for light as well as heavy work. It is also the practice in some shops to use spring steadyrests almost exclusively. Satisfactory results can doubtless be obtained with each type, under favorable conditions. When the work is light and flexible, the spring type is often used in preference to the fixed form. On the other hand, when a heavy rigid piece is being ground, solid unyielding steadyrests are commonly employed to provide as solid a support as possible, in order to absorb vibration and prevent chattering. Practically all spring steadyrests are capable of being locked, so that they are rigid enough, in most cases, to be applied to both heavy and light work.

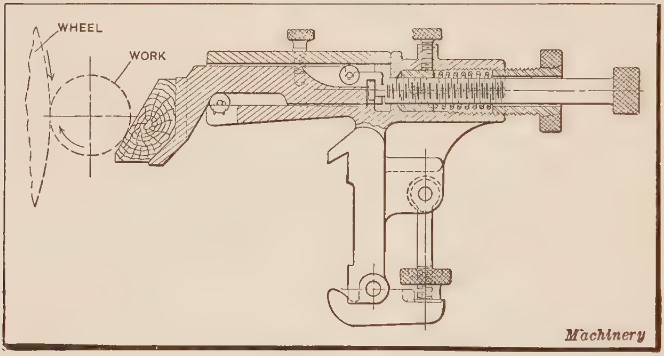


Fig. 8. Plain Type of Steadyrest used Principally on Universal Grinding Machine

There is a difference of opinion regarding the subject of steadyrests, not only as to the best type to employ, but also as to the advisability of using them under different conditions. Some have contended, that, while they are necessary in the case of long slender work, they are not required when grinding shorter and comparatively stiff pieces. At the present time, however, it is quite generally recognized that the use of a back-rest is an advantage in practically all cases, especially in connection with commercial grinding, when accuracy combined with the maximum output is desired. Some grinding machine operators dispense with steadyrests when the work is not very long, and when one or two pieces need to be ground, but even in such cases it is doubtful whether it pays to do without them. The present tendency is to use steadyrests quite liberally.

Spring Steadyrest of Plain Type. — One of the simplest types of steadyrests is shown in Fig. 8. This is called a plain steadyrest and is only used where the work can be more conveniently ground with a slight additional support. It is not universally adjustable and consequently its range is limited. In steadyrests of this kind, shoes of both metal and wood are used; for hardened work, as a rule, shoes made from bronze are found to give the best results. The shoes are shaped to suit the work, and, usually, instead of having a bevel as shown, the surface is curved to fit the diameter of the work being ground. When only a few pieces of one size are being turned out, however, the shoes for steadyrests of this type are generally made from wood because they can be more easily made and fitted than metal shoes.

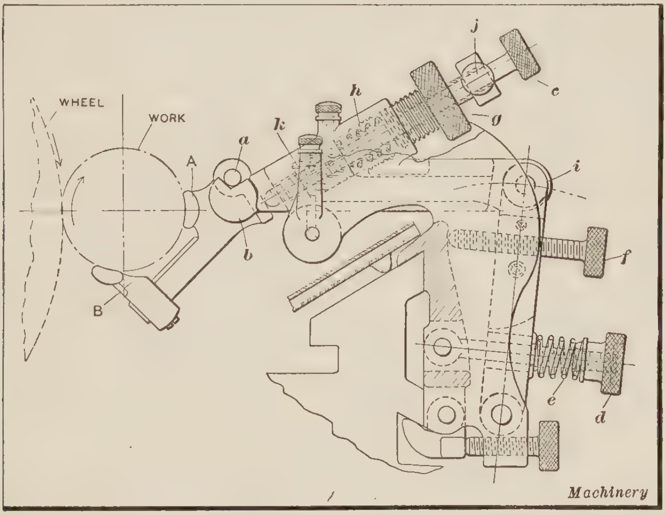


Fig. 9. Universal Type of Spring Steadyrest for Brown & Sharpe Universal Grinding Machine

Universal Steadyrest. — A steadyrest of the universal type, adapted for use on the No. 1 Brown & Sharpe universal grinding machine, is shown in Fig. 9. This steadyrest is universal in all its movements and capable of very delicate adjustment. The solid shoe used in this rest is generally made of bronze and a different size is required for each variation in diameter of the work. This type of rest is particularly adapted to work requiring a high degree of accuracy, and especially for shafts that are key-seated or under 1 inch in diameter. Its use is recommended where a large volume of work of one diameter is to be done. The same steadyrest, however, with adjustable shoes (see Fig. 9) can be used when there is considerable variation in diameter.

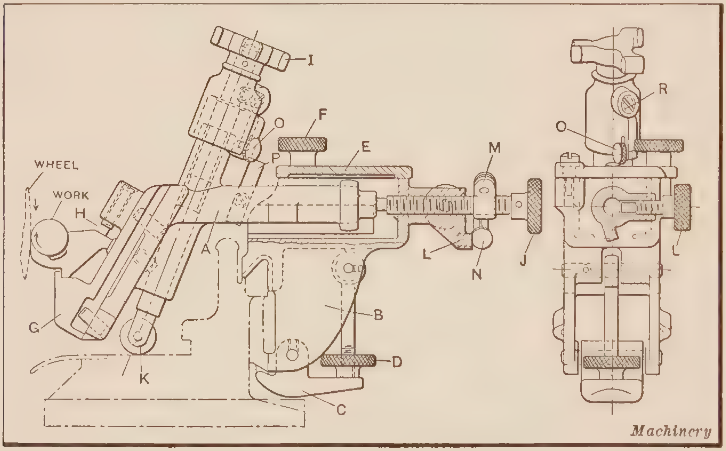
The method of operating this steadyrest is as follows: First, select a shoe of the size of the work being ground and hook the trunnion *a* in the V-support *b*. Then turn screw *c* back far enough to allow the shoe to clear the work and loosen the nut *d* to relieve the pressure on spring *e*. Then turn back screw *f*. Next turn screw *g* forward until a light pressure is given to spring *h*. Screw *c* should now be turned forward, and, if spring *e* is wholly relieved and screw *f* is back far enough, the shoe will come in contact with the work at both points *A* and *B*. A slight pressure should now be exerted on trunnion *i* to hold the shoe in contact with the work, and screw *f* should be carefully tightened, noting the slightest touch of the end of the screw against the stop, so that none of the parts will be moved. With this screw still in contact with the stop, the shoe should bear equally at both points *A* and *B*. Nut *d* should then be tightened to increase the pressure on spring *e*. The combined pressure on springs *e* and *h* should be just sufficient to resist the pressure of the wheel when taking the last cut on the work and to prevent vibration of the work under any cut that it may be desired to take. After the proper adjustments have been made, clamping screw *j* should be tightened, to prevent screw *c* from loosening.

The next step is to grind a trial piece of work; at this time screw *c* is moved to maintain the contact of the shoe with the work, and screw *f* is adjusted to preserve the relative diameters at the various points. As the work approaches the finished size, it should be measured after each cut, where the different steadyrests make contact with it. After the trial piece is finished with the diameters alike at all points, the shoe should bear equally at points *A* and *B* and the sliding nut *k* should rest against the shoulder. The parts should now be left in this relation and another piece of work ground, adjusting the screw *c* only as the shoe wears and screw *f* for slight changes of the diameter. The effect of this adjustment should be noted on the work by the sparks from the wheel. When short stiff pieces are being ground, the cylindrical form is obtained from the machine centers, but when the work is long and flexible, the control of the centers is limited and they only steady the ends; consequently, in order to grind a slender shaft or rod cylindrical from one end to the other, it is necessary to rely on the adjustment of the work-rests.

With the various screws properly adjusted, the springs of this steadyrest cannot push the work beyond the required size. When the work is finished to size, nut *k* and screw *f* should rest against the shoulder and stop, respectively, so that further pressure of the springs is impossible. The shoe and wheel will then be left in the proper position for sizing duplicate pieces. It is necessary, however, to get the relative pressures of springs *e* and *h* correct. When unground work is placed on the centers of the machine and in the shoe bearings, the nut *k* and screw *f* will be forced away from the shoulder and stop, thus compressing the springs *e* and *h*. Should the shoe bear unequally at points *A* and *B*, tighten screw *d* to increase the pressure at *A*, and screw *g* to increase the pressure at *B*. The combined pressure of springs *e* and *h*, however, should not be greater than is necessary to support the work, as long, slender work, although of uniform diameter, may not be straight when released from the shoes unless some allowance is made for the elasticity of the material. When adjustable bronze shoes are used to support pieces of various diameters, first loosen the screw which clamps the lower bearing shoe, and adjust it until the work bears centrally on both shoe surfaces, then retighten the set-screw.

Rigid or Solid Type of Steadyrests. — The steadyrest shown in Fig. 10 is known as the rigid or solid type and is used wherever possible on Norton 6-inch and 10-inch machines. It is particularly adapted for carrying hardened and ground work-shoes and is used especially where exact duplication of work is required, say, to limits of 0.0005 inch. For the 6-inch machine, this steadyrest has a range of from $\frac{1}{4}$ to $2\frac{1}{2}$ inches in diameter, and for the 10-inch machine from $\frac{1}{4}$ to 4 inches in diameter. Hardened work-shoes are used only when the work is standard, that is, where a number of pieces of the same size are being made, but for jobbing work, wooden shoes are used in place of the hardened ones.

In applying the solid type of steadyrest, the shoe should be brought up firmly against the work while in the rough, whether the work be out of round or not. Grinding machine operators, as a rule, hesitate to do this because they see the shaft sprung out of line and wabbling back and forth. The irregularity of contour, however, which causes displacement, does not appreciably affect the final accuracy of the ground part. The reason for this is, that, as the roughness is removed, the lateral displacement becomes less and less, and finally disappears altogether when the work is true. Then the steadyrests that support the work longitudinally may be adjusted for the finish-grinding.



Machinery

Fig. 10. Rigid Type of Steadyrest adapted to 6- and 10-inch Norton Plain Grinding Machines

The method of applying and operating the steadyrest is as follows: The adjustable support *A* can be raised, lowered, or moved longitudinally, and the body *B* is quickly clamped on the machine with clamps *C* and thumb-nut *D*. The cover *E* is held in place by a thumb-screw *F*, and, when this screw is released, can be swung on a pivot to permit the removal of the adjustable support *A*. The work-shoe is hardened and ground to size, this shoe being quickly put in place or removed from the holder *G* by means of a screw *H*. It has a bearing in the holder on three points, thus insuring rigidity.

The vertical adjustment of the shoe is secured through knob *I* and the horizontal or back-and-forth adjustment through screw *J*. The roll *K* moves freely on the level surface of the work-table and allows free horizontal motion of work that is not true and straight before grinding. The knob *L* is used to clamp the screw *J* when necessary. The adjustable stop *M* is threaded onto the screw *J* and allows free motion until the correct size is obtained on the first of a number of duplicate pieces that are to be ground. Then stop *M* is made fast to the screw *J* by clamping screw *N*. The screw *J* can then be turned back to allow an unground piece of work to be placed on the centers and ground. This screw is then adjusted from time to time as the grinding proceeds until the stop-screw is reached, which limits further motion of the work supports and gives accurate duplication of work; the stop-screw (not shown) in stop *M* also allows delicate adjustment for the exact size of work to be obtained. Stop-screw *O* serves the same purpose for the vertical adjustment of the rest, coming in contact with stop *P*. The clamping screw *R* fastens the stop firmly to the shoulder on knob *I*. Wooden work-shoes

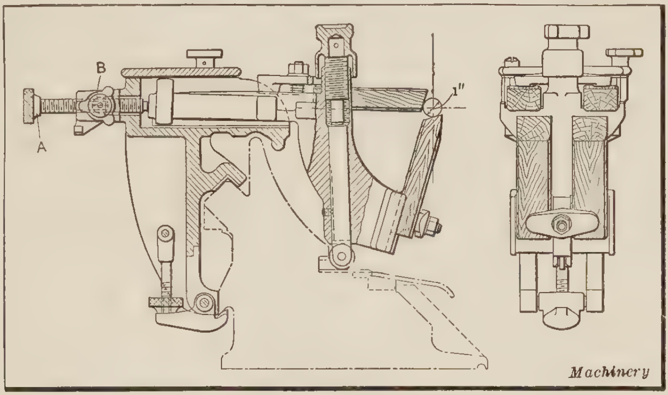


Fig. 11. Rigid or Solid Type of Steadyrest adapted to 14-, 18-, and 20-inch Norton Plain Grinding Machines

can be used in this steadyrest, instead of hardened shoes, where only a small number of pieces are to be ground.

The steadyrest shown in Fig. 11 is also of the fixed or solid type and is used on Norton 14-, 18-, and 20-inch machines, each rest being supplied with a set of four hard wooden blocks, two on the horizontal support and two on the angular or vertical supports. This steadyrest is fastened to the machine in the same manner as that shown in Fig. 10, but the method of adjusting the supporting shoes is somewhat different. In this case the horizontal supports are not adjustable up or down from the center of the work, but can be adjusted horizontally, and are held in place by means of a toe clamp. The position of the vertical shoes is controlled by the screw *A* provided with a locking nut *B*. The angle on the lower shoe is changed for different diameters of work, as will be described later in connection with different types of work-shoes. This type of steadyrest is also provided with shoes made from different materials. For large-diameter work, the lower shoes are made of cast iron instead of wood. This type of steadyrest

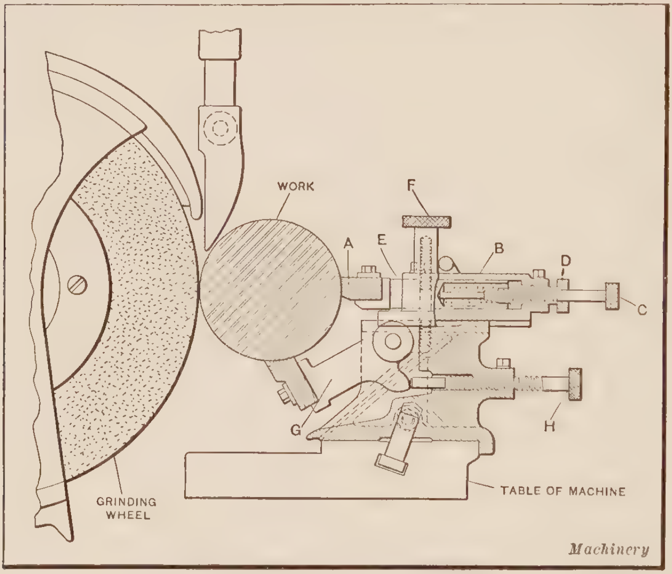


Fig. 12. Rigid Type of Steadyrest for Landis Plain and Universal Grinding Machines

is never used to support work of a long slender nature, but is used chiefly for supporting parts of large diameter, the wooden shoes being used for work up to about 4 inches in diameter and the iron shoes for larger diameters, up to the full capacity of the machine.

The steadyrest shown in Fig. 12 is also of the fixed or stationary type, but is constructed somewhat differently from those just described. This steadyrest is adapted to the Landis plain and universal grinding machines, and the two work-supporting shoes are operated independently. The horizontal shoe is carried in a plunger that is kept outward by means of a spring *B* and is backed up by an adjusting screw *C*. The tension of the spring is adjusted by means of screw *D*. Plunger *E* can be clamped rigidly in any position by means of the clamping screw *F*. The lower work-shoe support *G* is actuated by the adjusting screw *H*, which is operated to keep the work-shoe in contact with the work as the diameter of the latter is reduced by the grinding wheel. Where hardened work or large quantities of any particular part are being ground, the wooden blocks can be replaced by bronze or hardened steel blocks, depending on the number of pieces to be turned out.

The spring with which the horizontal support is equipped is used only in the case of grinding light delicate work, and then the support is only controlled by the spring until the work has been trued up; after this the support is held rigid by the adjustable screw. When using the spring, it is adjusted with sufficient tension to give a light support to the work, and, at the same time, follow the work if it runs out of true without springing it out of line. Usually (according to the practice of the Landis Tool Co.), when using the spring support, the work is spotted or ground true just at the point of support by feeding the wheel directly in without any traversing movement. After this the rest-jaw is brought up against the work rigidly by the independent adjustable screw for this purpose. The spring tension is controlled entirely independent from the rigid screw adjustment.

Combination Plain and Rigid Steadyrest. — Fig. 13 shows a combination plain and rigid steadyrest that is applied to the

Brown & Sharpe plain grinding machines. This rest is especially adapted for supporting large heavy work. The upper member of the steadyrest is similar to the one shown in Fig. 9, and the horizontal shoe *A* is operated in a similar manner. The lower steadyrest shoe is operated by means of plunger screw *B* in the manner shown more clearly in the sectional view to the right. Here it will be seen that screw *B* draws a tapered block *C* back and forth in a slot in screw *D*. Screw *D* also serves as a pivot upon which adjustable shoe *E* can be used for elevating above the range obtained with the adjustable wedge. As the diameter of the work is reduced, knob *F* is adjusted, the other support being taken care of by the spring or self-adjusting member of the steadyrest. Different types of shoes are provided with this steadyrest, as shown at *H* and *I*; the one at *H* is for comparatively small-diameter work, whereas the form at *I* is adapted to large-diameter work.

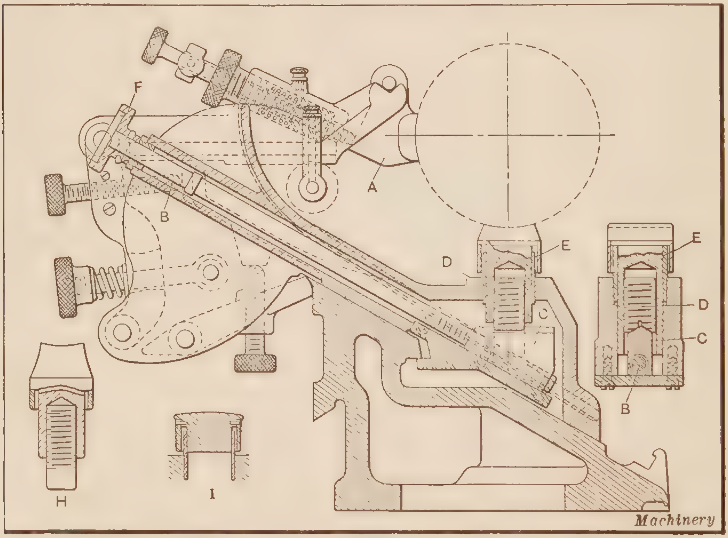


Fig. 13. Combination Rigid and Adjustable Steadyrest adapted to Brown & Sharpe Plain Grinding Machines

Steadyrest having Automatic Adjustment. — The steadyrest shown in Fig. 14, which is adapted to the Pratt & Whitney plain grinding machine, is of such construction that the work-shoe automatically follows up and supports the work as the grinding progresses. The proper relation between the work and shoe is maintained by the downward movement of the lever *A* which raises the shoe-holder *D* and the shoe as the work is reduced in diameter. This downward movement of lever *A* causes roll *B* to advance along its path which has sufficient inclination to permit the back pressure to be taken by the roll without slipping. The pressure is governed by adjustable weights on lever *A* which are held in place by thumb-screws. When the work has been reduced to the required diameter, the shoe is withdrawn by returning roll *B* to its original position and raising lever *A* to its upper position, where it is held by catch *C*. Both radial and vertical adjustments are provided by means of adjusting screws, and the bracket can be removed from the table by a slight inward pressure on the eccentric binding clamp.

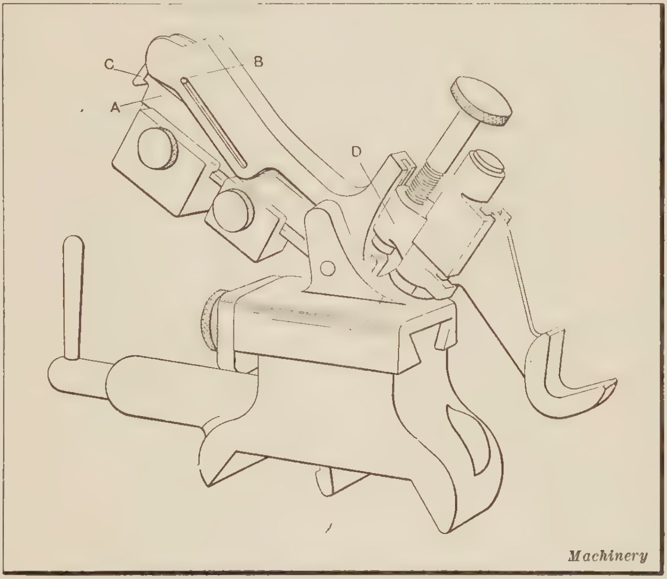


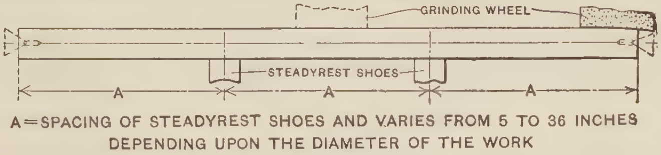
Fig. 14. Pratt & Whitney Steadyrest having Automatic Adjustment to compensate for Diameter Reduction of Ground Part

Follow Type of Steadyrest. — The follow type of steadyrest remains directly in front of the grinding wheel and supports the work as it is traversed past it. The bracket, in which the steadyrest shoe is supported, is clamped to the wheel slide, and, consequently, has no movement relative to the wheel. The work-shoe is generally made with a concave or V-face to suit the work and the pressure of the shoe is directed to hold the work up to the wheel. This shoe is adjustable by means of a screw and is not spring-controlled. This type of steadyrest can be used to advantage for grinding long slender work which must be brought to accurate dimensions.

Use and Location of Steadyrests. — Practically all grinding authorities agree on the fact that the more steadyrests used the greater will be the production; also, that there is rarely a case where the work can be ground to good advantage without the use of steadyrests. While this may be true as a general statement, grinding machine operators have not always followed the advice given, and, in many cases, only use steadyrests where they cannot possibly do without them. When grinding short rigid parts as, for example, a pin which is 1½ inch in diameter by 4 inches long, it is doubtful if much would be gained by using a steadyrest, but where the work is, say, 3 feet long and 1 inch in diameter, it would be practically impossible to grind it straight and true without a steadyrest; therefore, the number of steadyrests to use depends largely on the diameter and length of the work. No hard and fast rule can be laid down for the number of steadyrests to be used on any particular part, because this depends largely on the shape, diameter, and length of the work. Usually, however, steadyrests are located about 6 inches apart on work about 1 inch in diameter; the greater the diameter, the less the number of steadyrests and the greater the distances between them.

Table V gives the spacing of steadyrests as recommended by the Landis Tool Co. for work varying in diameter from ½ inch to 12 inches and in length from 6 inches to 84 inches. This table applies particularly to straight plain work. In the case of such pieces as armature shafts and similar work, where there are a number of sizes or diameters on the same piece, the piece is more rigid in the center on account of having a larger diameter at this point, so that the spacing of the steadyrests is dependent largely on the judgment of the operator. For instance, in case the piece should be of a certain length and certain size at the ends and much larger in the center, it might be sufficiently rigid to make the use of a steadyrest unnecessary, although the efficiency of the grinding operation can be increased in practically all cases, by the application of suitable supports. If the work were of the same diameter along its entire length, it probably would be necessary to use one or several steadyrests, in order to support it rigidly. In general, the number of steadyrests to be used should be governed largely by the smallest diameter of the work being ground, especially if the smallest diameter is located next to either the headstock or tailstock centers. Of course, the point on which the grinding is being done also has a considerable bearing on the position and number of steadyrests used. In the following examples of plain cylindrical traverse grinding, the steadyrests used on each job have been indicated, and from this it will be possible to draw conclusions as to where steadyrests should be used and the number required for various classes of work.

Table V. Minimum Number of Steadyrests Required for Supporting Plain Cylindrical Work


GRINDING WHEEL
STEADYREST SHOES
A
A
A
A=SPACING OF STEADYREST SHOES AND VARIES FROM 5 TO 36 INCHES DEPENDING UPON THE DIAMETER OF THE WORK

Diameter of Work in Inches	Length of Work in Inches										
	6	12	18	24	30	36	42	48	60	72	84
	Number of Steadyrests										
½ to 1 1/16	1	2	3	4	5	7	8	...	...	...	...
¾ to 1 5/16	..	1	2	3	4	5	6	7	...	...	...
1 to 1⅜	..	1	2	2	3	4	5	5	7	...	...
1½ to 1⅞	..	1	1	2	2	3	4	4	5	7	...
2 to 2⅜	..	..	1	1	2	2	3	3	4	5	6
2½ to 2⅞	..	..	1	1	2	2	2	3	4	5	5
3 to 3⅞	..	..	1	1	1	2	2	2	3	4	5
4 to 4⅞	..	..	..	1	1	1	2	2	3	3	4
5 to 5⅞	..	..	..	1	1	1	1	2	2	3	3
6 to 7⅞	..	..	..	..	1	1	1	1	2	2	3
8 to 9⅞	..	..	..	..	..	1	1	1	1	2	2
10 to 12	..	..	..	..	..	...	1	1	1	1	2

Steadyrest Work-shoes. — The work-shoes used in steadyrests are made from hardened steel, cast iron, bronze, and various kinds of wood. Each material has some particular advantage on certain classes of work, and in the following some of the principal uses for the different types of work-shoes will be referred to briefly. At *A* in Fig. 15 is shown the simplest type of shoe, where only one is used. As a rule, this shoe is made from wood — generally hard maple or hickory. When the work is comparatively heavy, however, a wooden shoe is not recommended, but, as a rule, soft metal shoes are used instead. A wooden shoe, of course, has the advantage of being more readily adapted to the work than a metal one, and, where only a few pieces are being ground, a wooden shoe is recommended.

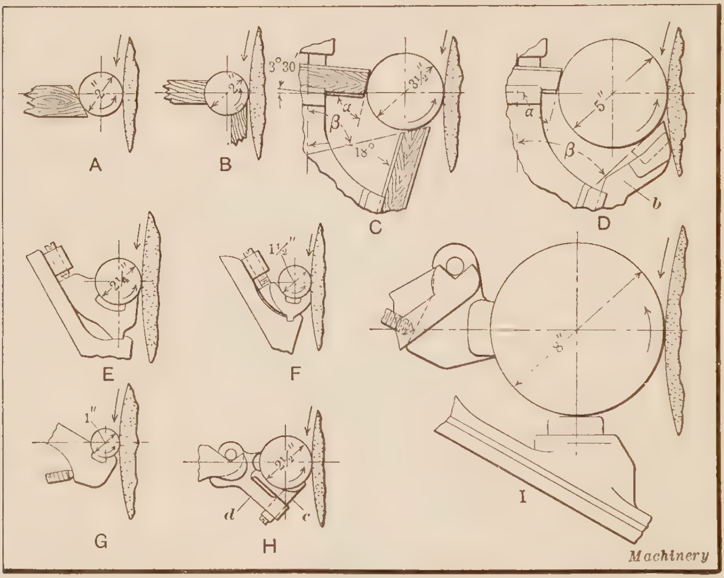


Fig. 15. Different Types of Work-shoes used on Grinding Machine Steadyrests

At *B* is shown another application of steadyrest shoes in which two shoes made from hard wood (either maple or hickory) are used. The best form of shoe for cylindrical grinding is that which forms two segments of an arc and covers about half the circumference of the work to be ground. Wood is the best material for a shoe of this kind; first, because of its cheapness, and, second, because of the facility with which it can be adapted to conform to the shape of the work. Shoes of the type shown at *B* should have two movements — one horizontal and one vertical. The amount of bearing surface of the shoe on the work should never be less in width than any slot or keyway that is in the work. In applying the shoes to the work, the lower shoe should be placed as near the wheel as possible, and the upper one on the center-line, as shown in the illustration.

Still another application of wooden shoes is shown at *C*. These shoes are for use in the rigid type of steadyrest and the angle is changed according to the diameter of the work, as given in the following table. Hard maple shoes are used for supporting work from 1 inch up to 4 inches in diameter, but on work larger than this and up to 8 inches in diameter, the lower shoe is usually made of bronze and is held in a special cast-iron holder *b*, as shown at *D*.

Diameter of Work, Inches	Angle α, Degrees	Angle β	
		Degrees	Minutes
1 to 3½	80	77	30
3½ to 4	80	62	30
4 to 5	80	47	00
5 to 6	80	58	00
6 to 8	80	67	30

Another type of work-holding shoe, which is used in the solid type of steadyrest, is shown at *E*; it is made from steel, hardened and ground to size. This shoe is quickly put in place or removed from the holder and is clamped by a screw. It is recommended for use on duplicate work, where a large number of pieces of one diameter are to be ground, and is of particular advantage on hardened work.

A shoe differing but slightly in construction from that shown at *E* is illustrated at *F*. This type of shoe is used in the production of small-diameter work on large size machines. It is made from a hardened and ground steel and is applied to the work as shown in the illustration. This type of shoe is also recommended for hardened work and for supporting parts that must be turned out in large quantities.

Still another type of shoe is shown at *G*. This shoe is generally adapted for a spring steadyrest; it is made from bronze, and a different size shoe has to be provided for each variation in the diameter of the work. It is particularly adapted for parts requiring a fine degree of accuracy and for shafts that are keyseated, and, in fact, for all work under 1 inch in diameter. Its use is strongly recommended where a large number of pieces of one diameter are to be ground.

The shoes shown at *H* are generally used in a spring type of steadyrest and are known as the adjustable type. The lower shoe *c* is adjustable along the bar *d* to accommodate various diameters of work. These shoes are made from bronze and are used where only a small number of pieces of one size are to be turned out.

On work of large diameter, where the ordinary spring rest is not sufficiently rigid to support it, the application of work-shoes as shown at *I* is recommended. In this illustration it will be noticed that two shoes are used to support the work against the thrust of the wheel. The horizontal shoe can, if necessary, be spring-operated or rigid, whereas the entire weight of the work is supported on an adjustable solid shoe, mounted in a holder and capable of adjustment in an inclined plane. In this way a great part of the weight of the work is taken off the centers of the machine and carried by the lower shoe, the other shoe additionally supporting the work against the thrust of the wheel and eliminating chatter and vibration.

As previously mentioned, the type of work-shoes used depends largely on the requirements of the work, its diameter, and the number of pieces turned out. When only a few pieces of a certain size are to be turned out, wooden shoes made from either hickory or hard maple are recommended. When a large number of pieces of small diameter are being made, the shoes illustrated at *E*, *F*, and *G* are recommended. Where large-diameter work is to be handled, the shoes illustrated at *D* and *I* are recommended.

Spotting for Steadyrests. — Before adjusting the rests, it is the practice, in some shops, to grind true "spots" for each of the supporting shoes preparatory to grinding certain classes of work, although this practice is not followed generally. In order to "spot" the work, the rests are first placed in their respective positions, and then the machine table is moved by hand until one of the rests is opposite the grinding wheel. The work is next "spotted" or trued by feeding the wheel in against the revolving work while the table remains stationary. The diameter of the surface ground in this way should be within, say, 0.002 inch of the finished size, although a larger allowance may be needed in certain cases. This "spotting" operation is repeated by successively placing each work-rest in front of the grinding wheel and proceeding as described.

When spotting a very flexible shaft, it is well to first grind a spot for the work-rest nearest the footstock, and then place this rest in position. The rest nearest the headstock is then located in the same manner and in this way a support is provided for the work while spotting for the rests in the center of the shaft. The practice of grinding spots is not to be recommended for ordinary work, and, in many shops, parts are never "spotted" prior to grinding, even when they are ground from the rough. When a part is of irregular form, if it is supported by rigid steadyrests and without spotting, the inequalities will gradually be reduced by the grinding wheel.

Lubricants for Cylindrical Grinding. — The problem of finding a suitable lubricant to carry off the heat is probably more important in grinding than in any other metal-cutting operation. The heat generated by the friction of the wheel on the work does not appreciably affect the wheel, but it distorts and injures the work, especially when it is hardened. The most common cooling medium used for grinding is plain water with enough sal-soda added to it to prevent rusting of the machine. Just enough sal-soda should be used in the water to show on the machine and the finished work when dry.

Grinding on a small variety of work in the tool-room is sometimes done dry, but for manufacturing grinding operations, dry grinding is not recommended. Work that will grind smooth with water or other cutting lubricants will often be subject to minute vibrations when grinding dry. There is apparently a rapid fluctuation of temperature which causes the work to recede from and approach toward the wheel very rapidly, thus leaving a mottled or rough surface. In order to obtain smooth and accurate work, the water should run upon the work smoothly and not fluctuate. A fluctuating supply will sometimes cause variation in the cut of the wheel, tending to mar the work, and will, as a rule, show a change of sparks.

In order to reduce the temperature of the work and maintain a uniform temperature while grinding, as well as to keep the wheel clean, various cutting compounds have been produced. The aim in view, of course, is to get some liquid which will have the maximum cooling effect on the work, and, at the same time, will not rust or gum the machine or mar the surface of the work. "Aquadag" is one of the commercial compounds used for grinding. A No. 10 jar of "Aquadag" is mixed with ten gallons of water; then $\frac{1}{2}$ pound of borax or sal-soda is added to prevent rusting. This lubricant should be applied to the work in the same manner as soda water.

The grinding of aluminum has always given more or less trouble, because, as soon as the work begins to heat, the chips cut out by the wheel do not free themselves, but clog the wheel and the wheel glazes rapidly, producing an unsatisfactory ground surface. Various lubricating compounds have been used for grinding aluminum; a lubricant composed of equal parts of light spindle oil and kerosene has been found to give satisfactory results. On one particular job of grinding, which was a small spindle made from cast macadamite, practically every cutting lubricant on the market, including soap, soda, and water, were tried without securing satisfactory results. The operator accidentally dropped some spindle oil on the work, while oiling up the machine, and this part showed a better finish after grinding than any other part of the work. A mixture of spindle oil and kerosene was then used, and the results were all that could be desired.

For form grinding, the Ford Motor Co. uses soap, sal-soda, lard oil, and water. This is made up in the following order:

First, a mixture of soap and lard oil of equal parts is boiled. While this is still hot, fifteen parts of water are added. The water, previous to being put in the soap and lard oil solution, is prepared with fifteen parts of water to one of sal-soda, and this proportion is varied according to the work upon which the lubricant is to be used. For form grinding vanadium steel drop-forgings, a mixture of fifteen parts of water to one of sal-soda is generally used.

The character and shape of the work has a considerable bearing on the cutting lubricant used. For instance, shoulder shafts which are not provided with recesses at the shoulders require a very thin lubricant. The reason for this is that the heavier lubricants collect in a mass at the shoulders and thus make it difficult for the operator to see when the wheel reaches the shoulder. For work of this character, a solution of sal-soda and water has been found most satisfactory.

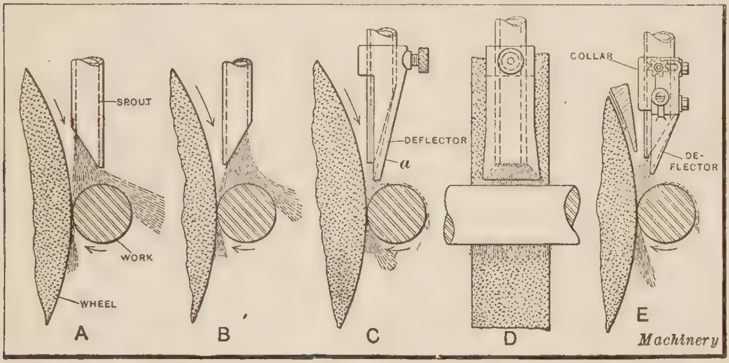


Fig. 16. Application of Water Nozzles to Cylindrical Grinding Machines

Shape and Action of Water Nozzles. — The application of water or other cooling mediums to the work when grinding is a matter that does not always receive the attention that it deserves. In rapid production work, in which the same care cannot be exercised as in tool-room grinding, it is necessary that every provision be made for eliminating those factors which tend to produce poor work. One of these factors is improper cooling. The first nozzles used in connection with universal grinding machines were small spouts held in a frame into which the water was conveyed by means of a pipe. These spouts discharged a very small stream of water onto the work which assisted somewhat in preventing excessive heating. With the wheels used at that time, the amount of water required was not very great, so that very little trouble was experienced in the nozzle arrangement.

Following the use of increased widths of grinding wheels, the problem of keeping the work cool became more difficult. The diagram, Fig. 16, shows some of the different types of water nozzles used. At *A* is shown a plain pipe nozzle; the position of this nozzle has been reversed, so that it works unsatisfactorily and has a tendency to splash the operator. The reason for this, is, that the water clings to the long side, so that it is thrown away from the wheel.

The proper way of placing a nozzle of the type shown at *A* is shown at *B*. In this case it will be noticed that the angular face is not presented to the wheel but away from it; even with this arrangement, however, there is considerable splashing of the water. One means of overcoming this is to use a deflector *a*, as shown at *C* and *D*, which can be adjusted so as to control the flow of the water. This prevents the water from splashing over the operator and directs it to the cutting point of the wheel on the work, where it is most needed. The lower end of the water nozzle spout and the deflector should be so shaped that the water is directed to cover the full face of the grinding wheel. If one or both edges of the wheel are allowed to cut dry, the surface finish may be marred by feed lines, so that to secure good work it is necessary to cover the entire cutting surface of the wheel with the cooling lubricant.

The diagram at *E* shows another type of adjustable water nozzle, in which case the deflector cannot only be moved up and down by adjusting it along the pipe, but it is also capable of an in-and-out movement that enables the operator to direct the stream of cooling lubricant where it is most needed. This nozzle is also so constructed and adjusted that the stream of water or cutting lubricant is directed to cover the full face of the grinding wheel.

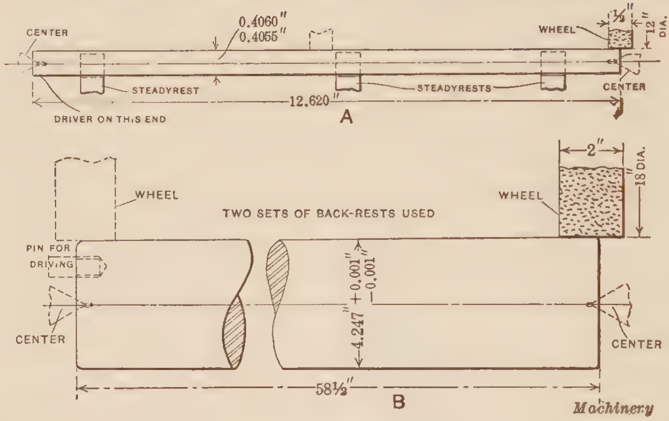
Amount of Cooling Lubricant to Use. — There are several conditions governing the amount of water or other cooling lubricant to use for cylindrical grinding:

1. The larger the work, the greater the wheel surface in contact; hence the necessity for a greater supply of cutting lubricant.
2. An increased width of wheel-face increases the amount of surface contact and necessitates a greater amount of lubricant.
3. An increase of work speed necessitates an increase in the amount of cooling lubricant.
4. Some materials require more cooling lubricant than others. For instance, hardened steel requires more cooling lubricant than soft steel, if satisfactory wheels are used in both cases.

In all cases, the water supply should be sufficient to keep the work as cool as possible, and, at the same time, cover the entire face of the grinding wheel. Usually the pump supplied with the grinding machine is capable of being speeded up so that the amount of water supplied to the machine can be varied independently of the position of the valve opening in the supply pipe.

The pumps supplied with the plain type of grinding machine are generally of the centrifugal or rotary type and vary in capacity from 5 to 100 quarts per minute. The pump is rotated at from 500 to 1200 revolutions per minute. The amount of cooling lubricant generally required for plain cylindrical grinding operations varies from 1 to 30 gallons per minute. For a wheel having, say, a 2-inch face, and grinding by the traverse method, the amount of cooling lubricant supplied would be in the neighborhood of from 3 to 5 gallons per minute. Of course, the amount of lubricant required is dependent entirely upon the width of wheel used, speed of work, and nature of material, and as the capacity of the pump can be increased, it is a comparatively easy matter to secure the desired amount of cooling lubricant.

Examples of Plain Cylindrical Grinding. — Grinding is such a broad subject, and the methods of accomplishing various results differ so widely, that a study of examples taken from actual practice will enable one not experienced in this work to obtain a more definite idea of speeds, feeds, etc., than would be possible from a general explanation of the common methods of procedure.



A

Work: — Sewing machine shaft, 0.20 per cent carbon steel, casehardened.

Operation: — Grinding entire length of shaft with a Norton (elastic) alundum wheel, grain 36, grade 5; 12 inches diameter, ½ inch face; speed 1910 R.P.M. — 6000 feet surface speed; work speed, roughing, 218 R.P.M. — 23 feet surface speed; work speed, finishing, 306 R.P.M. — 34 feet surface speed; amount removed from diameter, 0.006 inch.

Remarks: — Traverse method of grinding used at the rate of 30 linear inches per minute; roughing and finishing cuts taken; shaft reversed end for end; completely roughed out before finishing; 0.001 inch left on diameter for finishing; depth of cut, roughing 0.001 inch; 0.0005 inch, finishing; put through in lots of 500; approximate number of traverses, four roughing, four finishing; handled four times; production, 15 per hour, greatly limited on account of slenderness of work and care exercised so as not to remove casehardened surfaces; for roughing, two spring rests are used, and for finishing, a follow-rest is used. (See illustration.) Machine used, No. 11 Brown & Sharpe plain grinding machine.

B

Work: — Over-arm for milling machine, 0.20 per cent carbon machinery steel, not hardened.

Operation: — Rough- and finish-grinding external diameter; roughing with a Carborundum Co.'s aloxite (vitrified) wheel, grain 2411, grade L; 18 inches diameter, 2 inch face; speed, 1273 R.P.M. — 6000 feet surface speed; for finishing with a Carborundum Co.'s aloxite (vitrified) wheel, grain 40, grade M; 18 inches diameter, 2 inch face; speed 1167 R.P.M. — 5500 feet surface speed; work speed, roughing, 51 R.P.M. — 57 feet surface speed; work speed, finishing, 51 R.P.M. — 57 feet surface speed, and 70 R.P.M. — 79 feet surface speed; amount removed from diameter, 0.020 inch.

Remarks: — Traverse method of grinding used; for roughing, work is traversed past wheel six times at a traverse speed of 66 linear inches per minute, bringing work down to within 0.002 to 0.003 inch of finished diameter; 15 pieces to each truing of wheel; grinding time, 11.76 minutes; for finishing, work is traversed past wheel six times, five traverses at 66 linear inches per minute; last traverse at 25 linear inches per minute, rotated at 70 R.P.M. — 79 feet surface speed; four pieces to each truing of wheel; actual grinding time, 12.12 minutes; total grinding time, 23.9 minutes; machine used, Norton plain grinding machine.

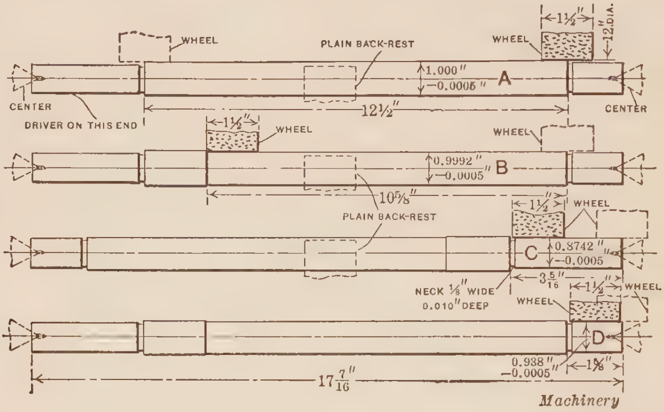
Fig. 17. Examples of Plain Cylindrical Grinding

Therefore, a variety of such examples are given in this and following chapters, with specific data so arranged that it can readily be referred to. In referring to these examples it should be remembered, that, while there are certain underlying factors that remain practically unchanged, it is nevertheless a fact that what would be considered good practice in one shop is not so considered in another; hence, there is more or less difference of opinion and variation in methods of procedure.

Grinding Long, Slender Shafts. — The first example, shown at *A*, Fig. 17, is that of grinding a long slender shaft. Such parts are quite difficult to grind; first, because of the liability of the work to spring and vibrate, and second, because of the difficulties met in securing accurate work. This shaft must be ground for its entire length to a limit of 0.0005 inch on the diameter. The liability to chatter and vibrate is largely overcome by the use of steadyrests.

The over-arm for a milling machine, shown at *B* in Fig. 17, is easier to grind than the slender shaft just referred to. The work is of such large diameter that a hole can be drilled in the end to carry a driving pin, so that it is not necessary to reverse the work end for end on the centers to complete it. For the grinding of this over-arm, a coarse-grain and comparatively hard bond wheel is used for both rough- and finish-grinding, so that, in order to get the required finish on the work, it is necessary to rotate the work faster for the finishing cut than for the roughing cut, and, at the same time, reduce the traverse speed of the work past the wheel.

Grinding Close to a Shoulder. — Occasionally it is necessary to grind close to a shoulder. This is often done by setting the wheel close to the shoulder with the hand adjustment and then feeding it straight in until the diameter next to the shoulder is reduced to the finished size or slightly above it; the remaining surface between the shoulder and the end of the work is then ground by using the power traverse movement in the usual way. The object in first grinding close to the shoulder is to provide a clearance space so that the wheel does not have to travel close up to the shoulder. Grinding may be done close to a shoulder without providing a clearance space by carefully adjusting the stroke dogs to reverse the table when the wheel is almost against the shoulder. When this method is employed, the dog, which controls the reversal at the shoulder end of the travel, must be accurately located to prevent the wheel from striking, and it may



Machinery

Work: — Clutch shaft for milling machine, 0.15 per cent carbon machinery steel, not hardened.

Operation: — Grinding four diameters with a Carborundum Co.'s (vitrified) aloxite wheel, grain 365, grade M; 12 inches diameter, 1½ inch face; speed, 1910 R.P.M. — 6000 feet surface speed; work speeds, 170, 190 and 200 R.P.M. — 46 feet surface speed; amount removed from diameter, 0.015 inch.

Remarks: — Traverse method of grinding used; on diameter (A) work is fed past wheel twice and wheel fed in to depth, then two traverses made with wheel "fixed"; table traversed at rate of 18 linear inches per minute; 15 pieces to each truing of wheel; grinding time, 5.9 minutes; on diameter (B) wheel is fed in to depth and work traversed twice past wheel at a table traverse of 18 linear inches per minute; 25 pieces to each truing of wheel; grinding time, 2.3 minutes; on diameter (C) wheel is fed in to depth on work and work traversed past it four times by hand, the first traverse at 10 linear inches per minute, and last three traverses at 20 linear inches per minute; 20 pieces to each truing of wheel; grinding time 2.02 minutes; on diameter (D) wheel is fed in to depth on work and work traversed four times past it by hand, the first traverse at 10 linear inches per minute, the last three traverses at 20 linear inches per minute; 30 pieces to each truing of wheel; grinding time, 1.49 minute; total grinding time for each shaft, 11.7 minutes; machine used, Norton plain grinding machine.

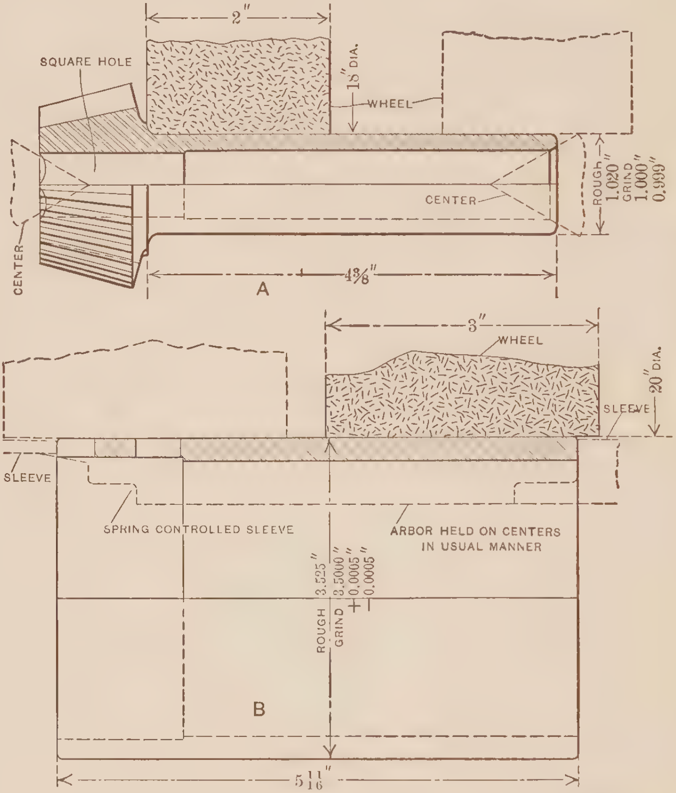
Fig. 18. Milling Machine Clutch Shaft ground on Four Diameters — Total Time 11.7 Minutes Per Shaft

be necessary to adjust this dog for each piece ground, because the center holes usually vary more or less in depth and any such variation would change the position of the shoulder with relation to the wheel. The result is that considerable time is wasted in adjusting the stroke, and for that reason the first method referred to is preferred by many. With the second method, the surface next to a shoulder is also likely to be left a little large, unless the wheel is allowed to dwell for a short time at the extreme end of the stroke.

When numbers of duplicate pieces are to be produced and a small fillet is allowed, the cylindrical portion may be roughed with the lathe and the shoulders can also be roughed, if the grinding machine is provided with a locating bar. By the use of this bar, the exact location of all shoulders can be secured by grinding, without necessitating any measuring. At the same time, the cylindrical portion can be ground with the same grinding wheel. The roughing in the lathe can be done with the same tool that roughs the cylindrical portion, because the lathe, in this case, is not required to give the shoulder any particular shape. When it is found best to locate and finish shoulders with the lathe, because there is no locating bar for the grinding machine, it may not be necessary to neck in at the shoulders for grinding; with a shoulder cut sharp by the lathe tool, the grinding does not materially change the corner. An efficient method, when no locating bar is at hand, is to rough the work in the lathe, leaving the shoulders about $\frac{1}{32}$ inch long and of whatever angle the rough-turning tool may form. Next grind the cylindrical portion, and, at the same time, square the shoulder with the grinding wheel. The work should then go to a lathe where a more skillful operator can locate the shoulders accurately; if a sharp corner is really necessary, it can then be made.

An example of shoulder shaft grinding is given in Fig. 18, which shows a clutch shaft for a milling machine. This is made from machine steel, not hardened. The work speed for all the diameters remains practically the same (about 46 feet surface speed), but the rate of traverse for grinding the various diameters is changed. For those shoulders which are comparatively short, the grinding is done by first feeding the wheel in to depth and then traversing rather slowly (10 inches per minute) by hand for roughing and quite fast (20 inches per minute) for finishing.

Grinding a Thin Sleeve. — The main drive gear bearing sleeve, shown at *B* in Fig. 19, is a difficult grinding proposition because of the thin walls of the sleeve and the liability to distort it while clamping to grind its external diameter. In order to obviate springing the work, it is held by the ends only, and floats on a special spring arbor. The external diameter is ground first, and then the bushing is located in a close-fitting sleeve chuck for grinding the internal diameter. In this way, both internal and



Machinery

A

Work: — Bevel main drive pinion, chrome-vanadium steel, oil-hardened.

Operation: — Grinding external diameter with a Norton (vitrified) alundum wheel, grain 24, grade M; 18 inches in diameter, 2 inch face; speed, 1100 R.P.M. — 5200 feet surface speed; work speed, 80 R.P.M. — 21 feet surface speed; amount removed from diameter, 0.020 inch.

Remarks: — "Step-in" method of grinding in conjunction with traverse for finishing is used; production, 25 to 30 pieces per hour; machine used, 10 by 36 inch Norton plain grinding machine.

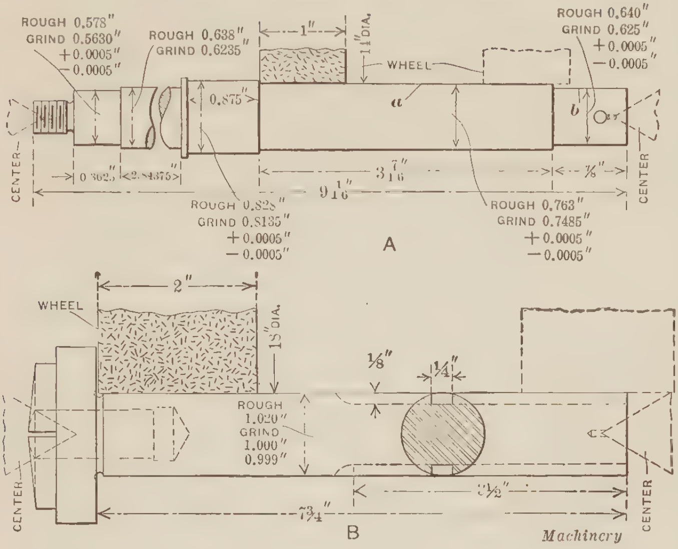
B

Work: — Main drive gear bearing sleeve, 0.15 carbon open-hearth Shelby seamless steel tubing, carbonized 0.030 inch deep and oil-hardened. Must strike 70 on the scleroscope.

Operation: — Grinding external diameter with a Norton (vitrified) alundum wheel, grain 24, grade M; 20 inches diameter, 3 inch face; speed, 1065 R.P.M. — 5576 feet surface speed; work speed, 82 R.P.M. — 74 feet surface speed; amount removed from diameter, 0.025 inch.

Remarks: — Power traverse is used and eight traverses at the rate of 56 linear inches per minute are required; wheel is fed in to a depth of approximately 0.003 inch per traverse for roughing out; production, 125 pieces in nine hours; machine used, 10 by 36 inch Norton plain grinding machine.

Fig. 19. Examples of "Step-in" and Traverse Methods of Grinding



A

Work: — Magneto and pump drive shaft, 0.50 per cent open-hearth steel, not hardened.

Operation: — Grinding external diameters with a Norton (vitrified) alundum wheel, grain 60, grade N; 14 inches diameter, 1 inch face; speed, 2000 R.P.M. — 7320 feet surface speed; work speed, 400 R.P.M. — 72 feet average surface speed; amount removed from diameter, 0.015 inch.

Remarks: — "Step-in" method of grinding in conjunction with traverse is used; two minutes to grind bearing (a); production, 240 for the large diameter (a), and 300 for the small diameter (b) in nine hours; machine used, Morse Twist Drill Co. plain grinding machine.

B

Work: — Transmission main drive pinion, chrome-vanadium steel, oil-hardened.

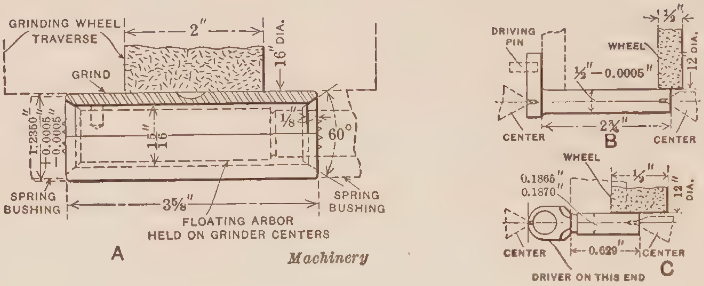
Operation: — Grinding external diameter with a Norton (vitrified) alundum wheel, grain 24, grade M; 18 inches diameter, 2 inch face; speed, 1100 R.P.M. — 5200 feet surface speed; work speed, 80 R.P.M. — 21 feet surface speed; amount removed from diameter, 0.020 inch.

Remarks: — "Step-in" method of grinding in conjunction with traverse is used; four cuts to finish work; remove 0.001 to 0.002 inch by traverse; three minutes each; machine used, 10 by 36 inch Norton plain grinding machine.

Fig. 20. "Step-in" Method of Grinding applied to Cylindrical Parts

external diameters can be ground concentric with each other, and the walls will be of equal thickness. For grinding this piece, a comparatively high work speed is used, but the power traverse feed is reduced below what would be necessary if a slower work speed were adopted.

Examples of "Step-in" Grinding Method. — As has been previously explained, a large number of concerns are not equipped with grinding machines capable of carrying wide face wheels, and



Machinery

A

Work: — Piston pin made from Shelby steel tubing containing 0.15 to 0.25 per cent carbon, carbonized 0.030 inch deep and hardened in oil.

Operation: — Grinding external diameter with a Norton (vitrified) alundum wheel, grain 46, grade K; 16 inches diameter, 2 inch face; speed 1600 R.P.M. — 6700 feet surface speed; work speed 176 R.P.M. — 56 feet surface speed; amount removed from diameter, 0.015 inch.

Remarks: — Wheel is fed in almost to depth, then traversed once across by hand; then power feed is thrown in and four traverses made at a traverse speed of 40 inches per minute; work held on a special arbor, two provided; production, 240 in nine hours; machine used, 10 by 36 inch Norton plain grinding machine.

B

Work: — Crank lever made from cast macadamite.

Operation: — Grinding stem with a Norton (elastic) alundum wheel, grain 120, grade 2½; 12 inches diameter, ½ inch face; speed, 2070 R.P.M. — 6500 feet surface speed; work speed, 459 R.P.M. — 60 feet surface speed; amount removed from diameter, 0.010 inch.

Remarks: — Traverse method of grinding used at the rate of 60 inches per minute; 0.0005 inch depth of cut per traverse of wheel; 120 pieces turned out to each truing of wheel; kerosene and spindle oil mixed half and half used as a cooling lubricant; production, 60 per hour; machine used, No. 11 Brown & Sharpe universal grinding machine.

C

Work: — Sewing machine plunger, 0.20 per cent carbon steel, casehardened.

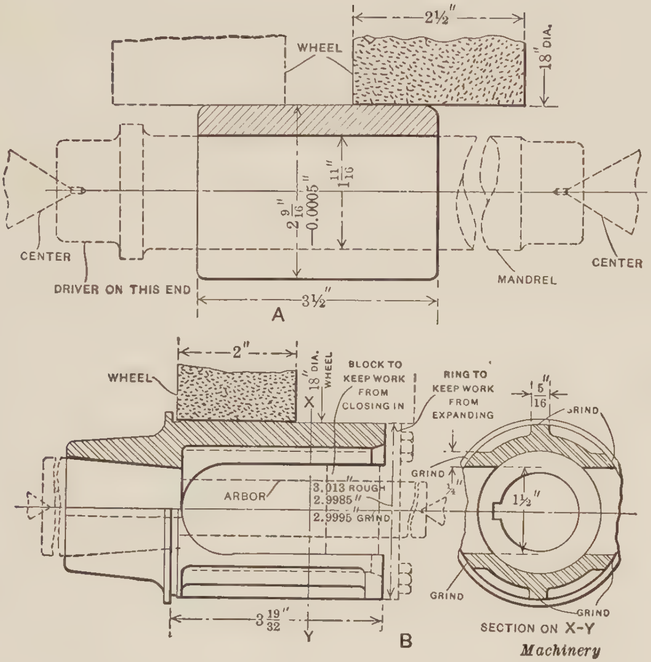
Operation: — Grinding external diameter of stem with a Norton (elastic) alundum wheel, grain 36, grade 5; 12 inches diameter, ½ inch face; speed, 1910 R.P.M. — 6000 feet surface speed; work speed, roughing, 510 R.P.M. — 25 feet surface speed; finishing, 714 R.P.M. — 35 feet surface speed; amount removed from diameter, 0.006 inch.

Remarks: — Traverse method of grinding used; table traversed by hand; approximate number of traverses, 4; put through in lots of 5000; production, 145 per hour; machine used, No. 11 Brown & Sharpe plain grinding machine.

Fig. 21. **(A) Grinding Shelby Tubing Externally. (B) Grinding Cast Macadamite. (C) Grinding a Small Plunger**

have endeavored to increase production by a method which is known as "step-in" grinding. This consists in "stepping" or feeding the wheel in at intervals along the work to within about 0.001 to 0.002 inch of the final diameter and then making several rapid traverses to finish. A good example of this class of work is shown at *A* in Fig. 19, which is a drive pinion made from a chrome-vanadium steel drop-forging, oil-hardened.

Another example of step-in grinding is shown at *A* in Fig. 20. This is a shaft made from high-carbon steel, not hardened. The



Machinery

A

Work: — Miter gear sleeve for milling machine, made from cast iron.

Operation: — Grinding external diameter with a Carborundum Co.'s (vitrified) carborundum wheel, grain 40, grade P; 18 inches in diameter, 2½ inch face; speed, 1273 R.P.M.— 6000 feet surface speed; work speed, 80 R.P.M. — 55 feet surface speed; amount removed from diameter, 0.015 inch.

Remarks: — "Fixed-wheel" method of grinding used; wheel fed in to depth and work traversed past wheel four times; first by hand at the rate of 15 linear inches per minute and last three times by power at 25 linear inches per minute; 30 pieces turned out per each truing of wheel; production, 30 per hour; machine used, Brown & Sharpe plain grinding machine.

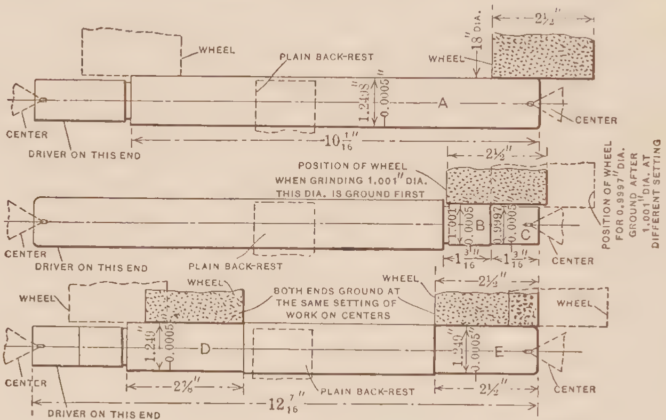
B

Work: — Universal drive shaft yoke, 0.20 per cent carbon, open-hearth steel, carbonized and hardened.

Operation: — Grinding external diameter with a Norton (vitrified) alundum wheel, grain 24, grade M, 18 inches in diameter, 2 inch face; speed, 1200 R.P.M. — 5600 feet surface speed; work speed, 80 R.P.M. — 63 feet surface speed; amount removed from diameter, 0.020 to 0.025 inch.

Remarks: — "Step-in" method of grinding used, in combination with one traversing cut; production, 20 per hour; machine used, Cincinnati plain grinding machine.

Fig. 22. (A) Grinding Sleeve or Bushing. (B) Grinding a Yoke held on a Special Arbor



Machinery

Work: — Fork shaft for milling machine, 0.20 per cent carbon machinery steel, not hardened.

Operation: — Grinding five diameters with a Carborundum Co.'s (vitrified) aloxite wheel, grain 365, grade M, 18 inches diameter, 2½ inch face; speed, 1273 R.P.M. — 6000 feet surface speed; work speeds, 140 and 180 R.P.M. — 46 and 47 feet surface speed; amount removed from diameter, 0.015 inch.

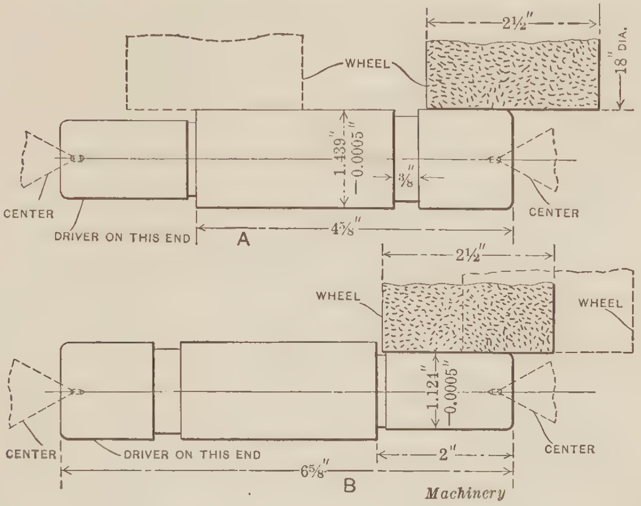
Remarks: — "Fixed-wheel" method of grinding used; for diameter (A) wheel is fed straight in to depth on work, which is traversed once past wheel by hand at 10 linear inches per minute, then power feed is thrown in and three traverses at 20 linear inches per minute are made; 7 pieces to each truing of wheel; grinding time, 4 minutes per piece; on diameter (B) wheel is fed in to depth, and work traversed four times by hand at 20 linear inches per minute; 20 pieces to each truing of wheel; grinding time, 1½ minute; on diameter (C) wheel is fed in to depth, and work traversed twice by hand at 20 linear inches per minute; 30 pieces to each truing of wheel; grinding time, 1.3 minute per piece; on diameters (D) and (E) wheel is fed in to depth, and work traversed twice by hand for each diameter at 20 linear inches per minute; 10 pieces to each truing of wheel; grinding time, 4.4 minutes for both diameters; total time to complete shaft, 9.9 minutes; machine used, Norton plain grinding machine.

Fig. 23. "Fixed-wheel" Method of Grinding applied to a Shaft

work was done on a comparatively light machine, and, in order to increase production, the "step-in" method was adopted.

Still another example of "step-in" grinding, in conjunction with table traverse, is shown at *B*, Fig. 20. This operation is done on a heavier machine than is used for part *A*, and, consequently, a medium bond coarse grain wheel is used. This example is in direct contrast to the one shown at *A* and represents the two methods that can be adopted to accomplish practically the same results on different types of machines with different wheels and wheel and work speeds.

Grinding Cast Macadamite. — A piece of work which gave considerable trouble before it was ground successfully is the crank lever shown at *B* in Fig. 21; it is made from cast macadamite.



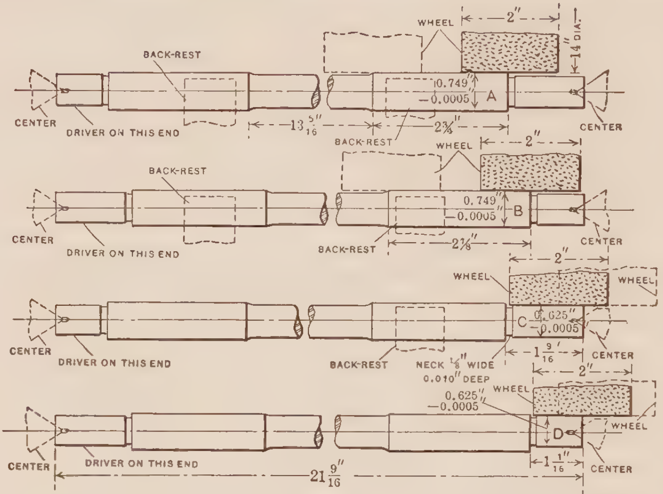
Work: — Intermediate shaft for milling machine, 0.15 per cent carbon machine steel, not hardened.

Operation: — Grinding two diameters with a Carborundum Co.'s (vitrified) aloxite wheel, grain 365, grade M; 18 inches diameter, 2½ inch face; speed, 1273 R.P.M. — 6000 feet surface speed; work speed, 128 R.P.M. — 38 and 49 feet surface speed; amount removed from diameter, 0.015 inch.

Remarks: — "Fixed-wheel" method of grinding used. On diameter (A) wheel is fed straight in to depth, and work traversed past it four times; the first time, by hand at 10 linear inches per minute and last three times by power at 22 linear inches per minute; 13 pieces to each truing of wheel; grinding time, 2.6 minutes; on diameter (B) wheel is fed straight in to depth and then work traversed past it four times at the rate of 20 linear inches per minute, by hand; 20 pieces to each truing of wheel; production, 15 shafts complete per hour; machine used, Norton plain grinding machine.

Fig. 24. Another Example of "Fixed-wheel" Grinding

This metal is similar to aluminum, except that it is a little softer. Practically every grade and grain of wheel was tried for this work without success, as well as various lubricating compounds. It was found that the work heated so much, due to the friction of the wheel in contact with it, that it was impossible to get a smooth surface. The problem was finally solved by using a mixture of kerosene and spindle oil, mixed in equal proportions, as a cooling lubricant. After this lubricant was tried, the wheels were again changed, using softer and harder bond as well as finer and coarser grain, but practically no change was noted on the work, showing that the lubricant solved the problem. It might also be mentioned that this cooling lubricant has been used with success while grinding cast aluminum.



Machinery

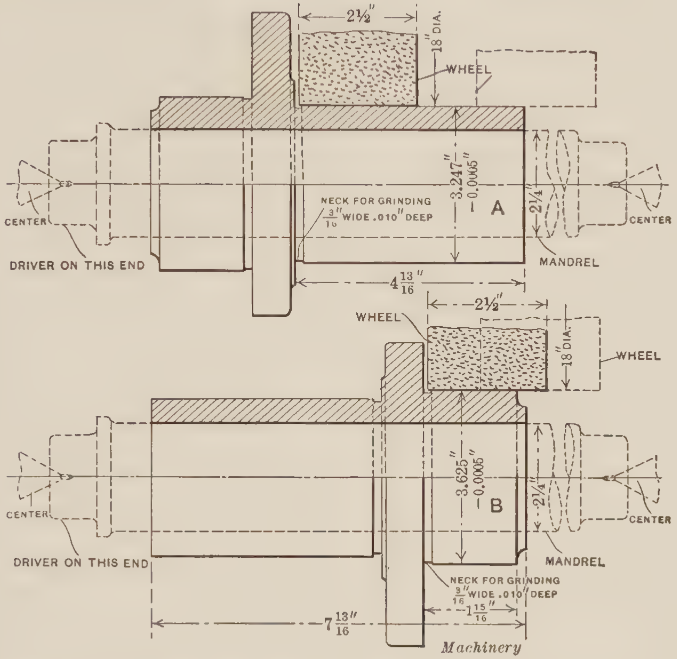
Work: — Reversing shaft for milling machine, 0.15 to 0.20 per cent carbon machinery steel, not hardened.

Operation: — Grinding four diameters with a Carborundum Co.'s (vitrified) aloxite wheel, grain 365, grade M; 14 inches diameter, 2 inch face; speed, 1637 R.P.M. — 6000 feet surface speed; work speed, 210 R.P.M. — 35 to 42 feet surface speed; amount removed from diameter 0.015 inch.

Remarks: — "Fixed-wheel" method of grinding is used; on diameters (A) and (B), wheel is fed in to stop and traversed four times past work by hand at 10 linear inches per minute for first traverse, 30 linear inches per minute for the last three traverses; 20 pieces per each truing of wheel; grinding time, 2.02 minutes for each end; on diameters (C) and (D), the wheel is fed in to depth and traversed past work four times by hand at the rate of 20 inches per minute; 20 pieces per each truing of wheel; grinding time, 1.69 minute for each end; total time, 7.42 minutes for each shaft; machine used, Landis plain grinding machine.

Fig. 25. Reversing Shaft for Milling Machine ground by "Fixed-wheel" Method

Examples of Grinding by "Fixed-wheel" Method. — The fork shaft for a milling machine shown in Fig. 23 was ground by what is known as the "fixed-wheel" method. In this case, the wheel was fed straight in on the work to a stop, and then traversed once past the wheel by hand feed and three times by power feed. Fig. 24 shows another piece ground in a somewhat similar manner, but, in this case, it will be noticed that no steadyrests are required on the work. Fig. 25 shows another milling machine part that is ground by the "fixed-wheel" method in conjunction with more than two traverses of the work past the wheel. These three examples illustrate practically similar conditions, with the exception of the application of steadyrests to the work.



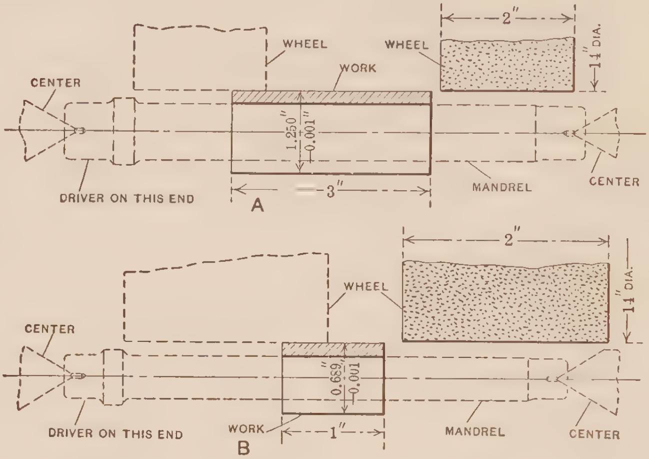
Work: — Gear-box bracket made from iron casting.

Operation: — Grinding two external diameters with a Carborundum Co.'s (vitrified) carborundum wheel; grain 40, grade P; 18 inches diameter, 2½ inch face; speed, 1273 R.P.M. — 6000 feet surface speed; work speed, 60 R.P.M. — 52 and 57 feet surface speed; amount removed from diameter, 0.017 inch.

Remarks: — "Fixed-wheel" method of grinding used; wheel is fed in to depth at shoulder and traversed past work four times, the first traverse at 15 linear inches per minute, the next three traverses at 30 linear inches per minute; on diameter (A) 30 pieces are turned out per each truing of wheel; actual grinding time 4.97 minutes; on diameter (B) 10 pieces to each truing of the wheel, actual grinding time, 4.13 minutes; total grinding time, 9 .10 minutes; machine used, Landis plain grinding machine.

Fig. 26. Cast-iron Gear-box Bracket or Bearing ground by "Fixed-wheel" Method

The gear-box bracket made from an iron casting that is shown in Fig. 26 is another example of the "fixed-wheel" method. The traverse of the wheel past the work varies from 15 to 30 linear inches per minute, the finer traverse being used for roughing and the coarser for finishing. The reason for the finer traverse for roughing is because of the heavy cut taken, whereas for finishing lighter cuts are used, and, consequently, higher traverse speeds can be employed.



A

Work: — Bushing made from cast iron.

Operation: — Grinding external diameter with a Carborundum Co.'s (vitrified) carborundum wheel, combination grain 46, grade N; 14 inches diameter, 2 inch face; 1728 R.P.M. — 6332 feet surface speed; work speed, 416 R.P.M. — 136 feet surface speed; amount removed from diameter, 0.025 inch.

Remarks: — "Fixed-wheel" method of grinding is used and work is fed past wheel twice at a table speed of 16 linear inches per minute; 50 pieces turned out to each truing of wheel; production, 100 in 1½ hour; machine used, Brown & Sharpe plain grinding machine.

B

Work: — Bushing made from Tobin bronze.

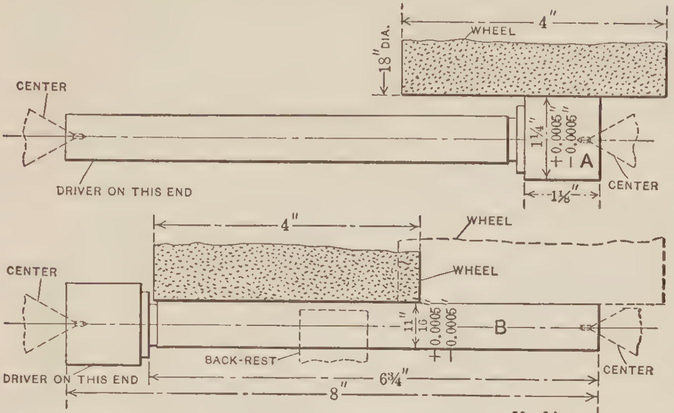
Operation: — Grinding external diameter with a Norton (vitrified) alundum wheel, combination grain 36, grade R; speed, 1728 R.P.M. — 6332 feet surface speed; work speed, 416 R.P.M. — 75 feet surface speed; amount removed from diameter, 0.020 to 0.025 inch.

Remarks: — "Fixed-wheel" method of grinding is used and two traverses of work past wheel at the rate of 16 linear inches per minute complete operation; wheel trued up once every day; production, 100 pieces in 45 minutes, or about 130 pieces per hour; machine used, Brown & Sharpe plain grinding machine.

Fig. 27. Cast-iron and Bronze Bushings ground Externally by "Fixed-wheel" Method

Two examples of bushing grinding are shown at *A* and *B*, in Fig. 27. The bushing shown at *A* is made from cast iron and is ground by the "fixed-wheel" method. The bushing shown at *B* is made from Tobin bronze and is also ground by the "fixed-wheel" method. For the grinding of the cast-iron bushing at *A*, a carborundum wheel is used, whereas for the Tobin bronze, an alundum wheel is used.

Combined "Straight-in" and Traverse Grinding. — Fig. 28 shows a pinion shaft that is ground by two methods. The short



Machinery

Work: — Pinion shaft, 0.30 per cent carbon steel, not hardened.

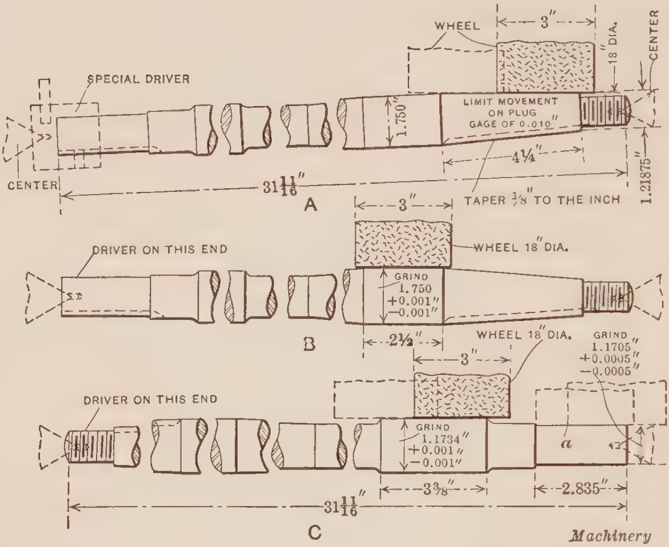
Operation: — Grinding two external diameters with a Norton (vitrified) alundum wheel, grain 24, grade M; 18 inches diameter, 4 inch face; speed 1650 R.P.M. — 6050 feet surface speed; work speed, 77 R.P.M. — 14 to 25 feet surface speed; amount removed from diameter, 0.020 inch.

Remarks: — "Step-in" method of grinding in conjunction with traverse grinding is used; order of operations is to first feed wheel straight in on diameter (A) and grind to size. Second, reverse work on centers, step-in twice on diameter (B) to within 0.001 inch of finished size, and then traverse the work past the wheel; 50 pieces turned out to each truing of wheel; production, 20 pieces per hour; machine used, 6 by 32 inch Norton plain grinding machine.

Fig. 28. Combined "Step-in" and Traverse Methods of Grinding applied to a Pinion Shaft

shoulder *A* is ground by feeding the wheel straight in on the work, whereas the shoulder *B* is ground by stepping the wheel in at intervals along the work and then making several rapid traverses. Advantage here is taken of the use of a wide face wheel, and it will also be noticed that a comparatively low work speed and a coarse grain, medium bond wheel has been used. This example represents good average practice.

The rear axle shown in Fig. 29 is an interesting example of this class of work. For grinding the taper bearing, the grinding wheel is fed in to depth at the end next to the tailstock, then withdrawn and moved over to the other end of the bearing and fed in to depth, after which three traverses of the wheel past the work are made. The machine table is, of course, set at the required angle. The grinding of this shaft necessitates three separate settings, and for all except operation *B* the wheel is traversed. For this operation the wheel is fed straight in on the work until the final



Work: — Material Carpenter's "Samson" No. 3 nickel steel, hardened in fish oil and tempered; allowance of 0.030 to 0.040 inch left on all diameters for grinding; method of grinding is to first feed wheel in almost to depth at the end next the tailstock, then travel over to the other end and feed to depth, and then make three traverses back and forth, using power feed, at the rate of 16 linear inches per minute; grinding limit varies on all diameters (see illustration); operations performed on a 12 by 42 inch Landis plain grinding machine; shaft must strike 60 to 70 hard on scleroscope.

Operation A: — Grinding taper with a Norton (vitrified) alundum wheel, grain 24, grade M; 18 inches diameter, 3 inch face; speed, 1580 R.P.M. — 7482 feet surface speed; work speed, 92 R.P.M. — 36 feet average surface speed; 16 pieces ground to each truing of wheel.

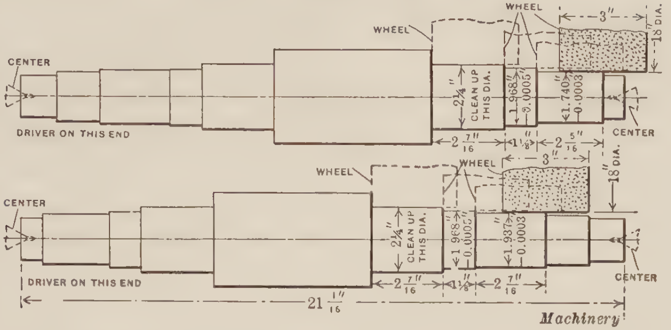
Operation B: — Grinding main bearing; wheel fed straight in on work; wheel is same grain and grade as above; production on this bearing, one piece in 35 seconds.

Operation C: — Grinding oil retainer fit with a Norton (vitrified) alundum wheel, grain 24, grade L; 18 inches diameter, 3 inch face; operating at same speed as above, but traversed; production time is 1 minute and 31 seconds each. At this same setting the differential bearing (a) is also ground by the same type of wheel, traversed at the rate of 16 inches per minute; time for this operation is 50 seconds.

Fig. 29. Rear Axle Shaft for Automobile ground by "Straight-in" and Traverse Methods

diameter is reached. Another point of interest in connection with the grinding of this part is the special driver. The requirements call for a certain length to be maintained between the taper bearing and the other end of the shaft, and to obviate the extreme care which is necessary to get all the centers of a certain depth, the special driver shown is used.

Grinding a Spherical Surface. — Fig. 31 shows two special grinding operations; one is the grinding of an upper end of a



Work: — Automobile worm drive shaft, alloy steel heat-treated.

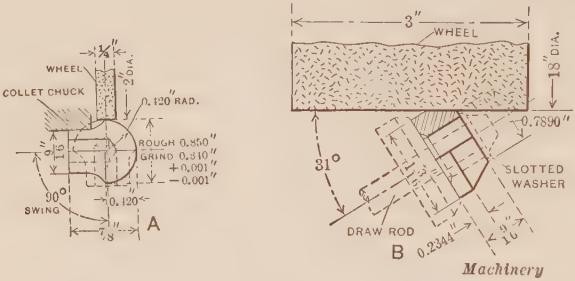
Operation: — Grinding six diameters with a Norton (vitrified) alundum wheel, grain 46, grade K; 18 inches in diameter, 3 inch face; speed, 1273 R.P.M. — 6000 feet surface speed; work speed, 75 R.P.M. — 40 feet average surface speed; amount removed from diameter, 0.020 to 0.030 inch.

Remarks: — Hand traverse is used for grinding all six diameters; the two diameters on each side of the worm are just cleaned up whereas the other two diameters indicated (see illustration) are ground to within close limits; twelve diameters ground per each truing of wheel; production, 35 shafts complete in 10 hours; machine used, Modern plain grinding machine.

Fig. 30. Plain Traverse Grinding Operation on Shouldered Shaft

valve push-rod, and the other, a cone for a fan shaft. The upper end of the valve push-rod is made from screw stock and is carbonized and hardened in oil. The grinding operation consists in finishing the radius on the head of this rod with a fine grain, medium grade, alundum wheel. The method of grinding this piece is to first bring the wheel in contact with the work at the shoulder and then swing the head of the machine around until it stands at right angles to the wheel. The wheel is then fed in on the work again. This procedure is continued until the radius has been ground, bringing the push-rod head to the required diameter.

Grinding a Conical Surface. — The cone for the fan shaft shown at *B*, Fig. 31, was taken from a light grinding machine and placed on a Landis plain grinder, using an old type Landis center grinder as a fixture for holding the work. The production was increased in this way from about 500 to 1200 pieces in nine hours, because of the greater rigidity and possibility of taking heavier cuts. The method of grinding this piece is to bring the wheel directly in on the work and then make a couple of rapid traverses for finishing. It will be noticed also, in this case, that a compara-



A

Work: — Upper end of valve push rod, screw stock, carbonized 0.030 inch deep and hardened in oil; 70 minimum hardness.

Operation: — Grinding radius on head with a Norton (vitrified) alundum wheel, grain 67, grade M; 2 inches diameter, ¼ inch face; speed, 12,800 R.P.M. — 6702 feet surface speed; work speed, 320 R.P.M. — 70 feet surface speed; amount removed from diameter, 0.010 inch.

Remarks: — Wheel is first brought into contact with work on shoulder, and then head is swung around until it stands at right angles to wheel, which at the same time is fed into work; production, 250 in nine hours; machine used, Rivett universal grinding machine.

B

Work: — Cone for fan shaft, 0.15 per cent carbon open-hearth steel, carbonized 0.030 inch deep and hardened.

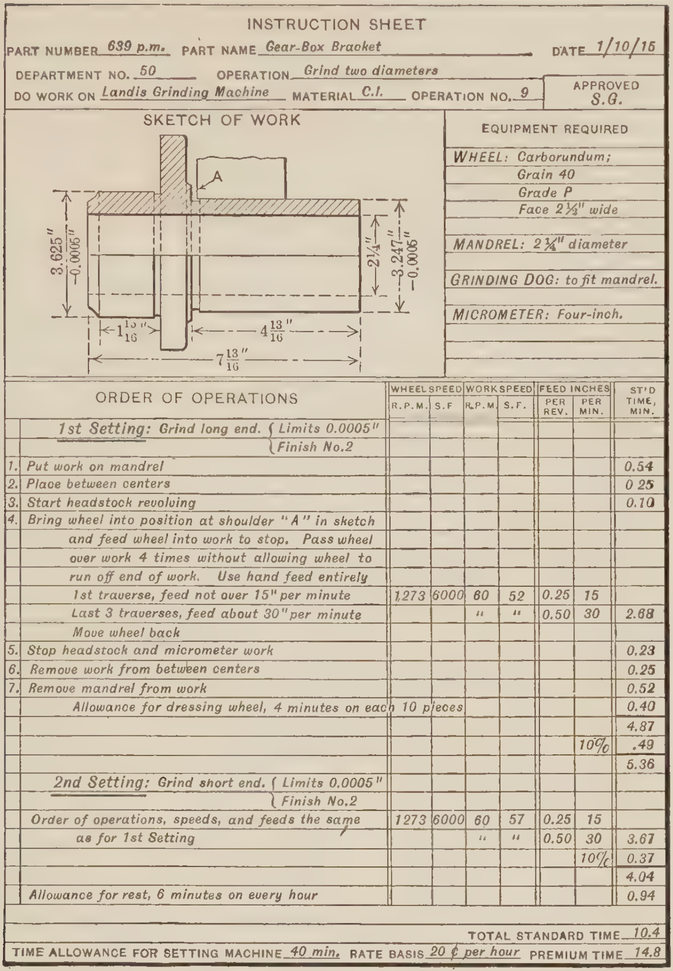
Operation: — Grinding cones with a Norton (vitrified) alundum wheel, grain 24, grade M; 18 inches diameter, 3 inch face; speed, 1760 R.P.M. — 8272 feet surface speed; work speed, 440 R.P.M. — 115 feet average surface speed; amount removed from diameter, 0.010 inch.

Remarks: — An old type Landis center grinder specially fitted up is used for holding work; wheel is fed in directly against work until cleaned up and then traversed to finish; production, 1200 in nine hours; machine used, Landis plain grinding machine.

Fig. 31. (A) Grinding Spherical End on Valve Push-rod. (B) Grinding Conical Surface

tively coarse grain, medium bond wheel is used and that it is rotated at a surface speed of 8272 feet, which is unusually high. In order to get the desired results, it is also necessary to increase the work speed, which, in this case, is above the average, being 115 feet average surface speed.

Instruction and Record Chart. — The foregoing examples of work indicate the various methods adopted for handling work that differs considerably in shape and nature of material. These examples are also a good indication of the advisability of keeping complete records of all grinding operations, so that when a new piece must be ground, it is not necessary to waste time in experimenting. The chart shown in Fig. 32, while used chiefly as a basis for setting piece rates, contains a number of important points that are valuable from an efficiency standpoint. The



INSTRUCTION SHEET

PART NUMBER 639 p.m. PART NAME Gear-Box Bracket DATE 1/10/15

DEPARTMENT NO. 50 OPERATION Grind two diameters

DO WORK ON Landis Grinding Machine MATERIAL C.I. OPERATION NO. 9

APPROVED S.G.

SKETCH OF WORK

A
3.625"
−0.0005"
2¼"
3.247"
−0.0005"
1 13/16"
4 13/16"
7 13/16"

EQUIPMENT REQUIRED

WHEEL: Carborundum;
Grain 40
Grade P
Face 2⅛" wide

MANDREL: 2¼" diameter

GRINDING DOG: to fit mandrel.

MICROMETER: Four-inch.

	ORDER OF OPERATIONS	WHEEL SPEED		WORK SPEED		FEED INCHES		ST'D TIME, MIN.
		R.P.M.	S.F	R.P.M.	S.F.	PER REV.	PER MIN.	
	1st Setting: Grind long end. { Limits 0.0005"							
	{ Finish No.2							
1.	Put work on mandrel							0.54
2.	Place between centers							0 25
3.	Start headstock revolving							0.10
4.	Bring wheel into position at shoulder "A" in sketch							
	and feed wheel into work to stop. Pass wheel							
	over work 4 times without allowing wheel to							
	run off end of work. Use hand feed entirely							
	1st traverse, feed not over 15" per minute	1,273	6000	60	52	0.25	15	
	Last 3 traverses, feed about 30" per minute			"	"	0.50	30	2.68
	Move wheel back							
5.	Stop headstock and micrometer work							0.23
6.	Remove work from between centers							0.25
7.	Remove mandrel from work							0.52
	Allowance for dressing wheel, 4 minutes on each 10 pieces							0.40
								4.87
							10%	.49
								5.36
	2nd Setting: Grind short end. { Limits 0.0005"							
	{ Finish No.2							
	Order of operations, speeds, and feeds the same	1273	6000	60	57	0.25	15	
	as for 1st Setting			"	"	0.50	30	3.67
							10%	0.37
								4.04
	Allowance for rest, 6 minutes on every hour							0.94

TOTAL STANDARD TIME 10.4

TIME ALLOWANCE FOR SETTING MACHINE 40 min. RATE BASIS 20 ¢ per hour PREMIUM TIME 14.8

Machinery

Fig. 32. Chart illustrating Method of keeping Complete Record of Grinding Data

example shown in the chart is a gear-box bracket for a milling machine on which two diameters are to be ground. The method of procedure is carefully outlined under the heading "Order of Operations."

The examples of work shown in the foregoing have not been chosen in all cases because they represent the best practice, but have been selected to illustrate the points that it is necessary to observe in grinding cylindrical work successfully. The examples shown illustrate work that is turned out on a manufacturing basis, and are not of the tool-room variety. The reason for this is that for several years the development of the grinding machine has been along the line of increasing production, at the same time retaining the necessary accuracy.

Plain and Universal Grinding Machines. — Cylindrical grinding machines, like milling machines, are divided into two general classes, known as plain and universal types. The first type is ordinarily used for grinding work in large quantities which varies comparatively little in form, which means that it is essentially a machine for manufacturing purposes. The general construction of a universal grinder is similar to that of a plain grinder of the same make, but it differs from the latter in having certain special features and auxiliary attachments which adapt it to a more general or universal class of work. The principal difference between the universal and plain types, as far as the construction of the machine itself is concerned, is as follows: The wheel slide of a universal machine can be swiveled with relation to the travel of the table; the headstock can also be set at an angle, and provision is made for revolving the headstock spindle for grinding parts that are held in a chuck or otherwise. With a plain machine, the wheel slide is permanently set at right angles to the table travel and the headstock cannot be swiveled. The machine shown in Fig. 2 is a universal type, whereas a plain grinder is shown in Fig. 33. These machines differ considerably in their construction because they are different makes. Plain and universal machines of the same make, however, are practically the same except for the changes referred to, unless one is much larger than the other, in which case, the design usually varies to some extent.

The machine illustrated in Fig. 33 operates by traversing the grinding wheel along the work which rotates in a fixed position, as indicated by the diagram *B*, Fig. 1. The travel of the wheel carriage is regulated for work of different lengths by varying the position of the dogs *N*, which are mounted on a wheel or circular rack. Worm-teeth are cut on the periphery of this wheel, and the dogs are held in any desired position by worms, which may be lifted out of engagement when the dogs are to be moved a considerable distance. The tappet *O* against which these dogs strike, thus reversing the movement of the carriage, can be swung out of the way when it is desired to allow the wheel to travel beyond the reversing points. The amount that the wheel carriage moves longitudinally per revolution of the work, or its side traverse, is regulated by changing the position of lever *I*. The lever *J* is used for reversing the carriage travel at any point, by hand, while the traverse movement is started or stopped by lever *K*. When it is desired to move the carriage longitudinally by hand, the wheel *L* is used. The platen *P* can be swiveled for grinding taper work, the same as with a universal machine. The power for traversing the wheel carriage is obtained from a belt operating on pulley *H*, and the work is rotated by a belt connecting with pulley *G*. The work speeds are varied by shifting lever *F*.

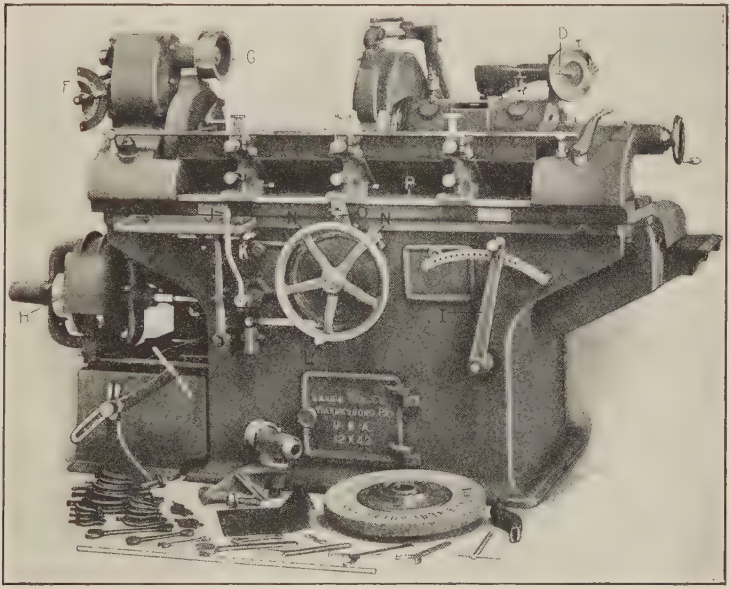


Fig. 33. Landis Plain Grinding Machine

The grinding wheel is moved to or from the work by the handwheel *D*. In conjunction with this handwheel there is an automatic cross feed which may be set to advance the wheel at each reversal of the carriage on which the wheel is mounted. This feed is effected by the pawl *A* (Fig. 34) which meshes with ratchet teeth in the periphery of the wheel *D*. Provision is made for automatically disengaging this feed when the wheel has ground any predetermined amount from the work. This is accomplished by a movable ring *B*, mounted on the handwheel and having a knock-out cam *C*, which engages a pin on the feed pawl *A*. When setting this feed to grind a given amount, the wheel is first brought into contact with the work, by turning the handwheel *D*; the ring *B* is then moved around until the cam *C* is against the pin on pawl *A*.

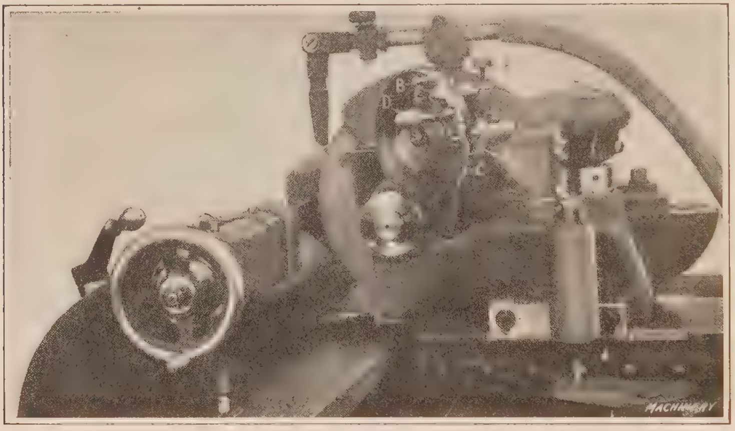


Fig. 34. End View of Landis Grinding Machine showing Automatic Cross-feed Mechanism

When the machine makes its first stroke, the pawl is disengaged from the ratchet. The wheel should then be allowed to pass over the work until it has practically ceased cutting, when the traverse should be stopped, say, at the footstock end. The diameter of the work is next measured carefully with a micrometer. The thumb-latch *E* is then pressed against its stop four times for each 0.001 inch reduction in diameter required. As this thumb-latch has attached to it a spring pawl engaging the ratchet teeth on the wheel *D*, the ring *B*, with its knock-out cam, is moved away from the feed pawl *A* an amount equivalent to one ratchet tooth each time the latch is pressed. When the grinding is continued, the

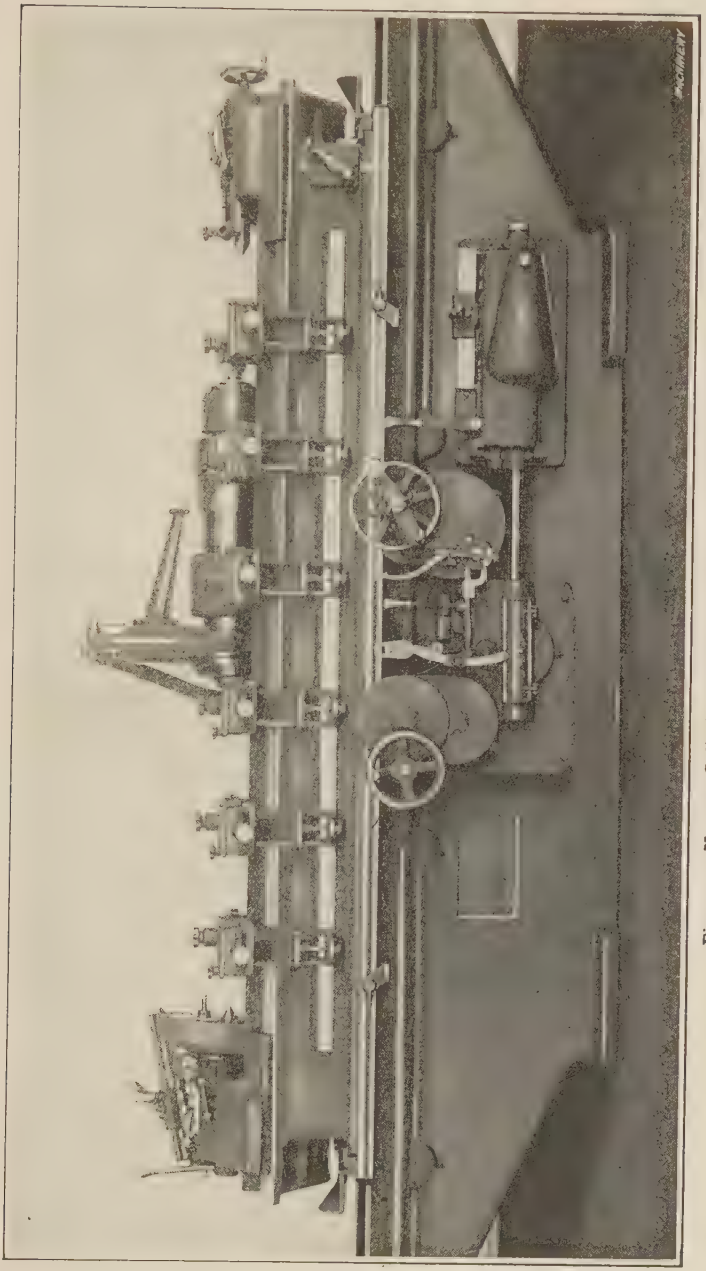


Fig. 35. Norton Cylindrical Grinding Machine of Plain Type

cam gradually moves backward and finally disengages the feed pawl. The amount of feed is regulated by adjusting screw *F*.

Large Grinding Machine of Plain Type. — Fig. 35 shows a large grinding machine of the plain type which will grind work up to 96 inches in length. This machine has a moving work-table, and the grinding wheel revolves in a fixed position, except for the crosswise feeding movement at each end of the stroke. The wheels used in this machine are 24 inches in diameter and have a width of 2 inches. The wheel slide is fed forward either by a handwheel or automatically, and the automatic feed can be set for grinding a given amount. The rotative speed of the work can be changed by shifting the belt on the driving cone pulley of the headstock. The rate of table traverse can also be regulated to give a coarse feed for removing stock rapidly or a finer feed for finishing. The mechanism seen at the front of the machine includes the automatic cross feed and the table speed-changing mechanism. There are also handwheels for adjusting the table longitudinally and the grinding wheel in a crosswise direction. The particular machine illustrated is equipped with six steady-rests which are used for supporting the work and to prevent vibration. The number of rests used, in any case, depends upon the length of the part being ground, as explained previously. This machine illustrates the heavier designs which are commonly

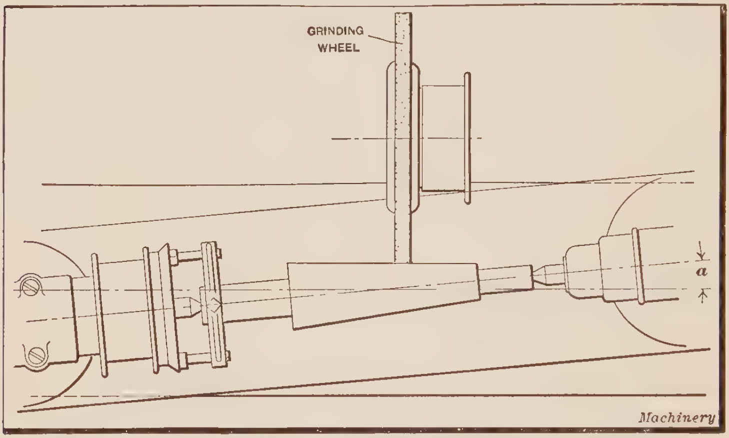


Fig. 36. Taper Grinding by Swiveling Platen to Required Angle

used in modern shops for grinding machine parts in connection with manufacturing.

Taper Grinding. — Taper parts are ground practically the same as those that are straight or cylindrical, provided the taper is not too steep or abrupt. The work is placed between the centers, as illustrated in Fig. 36, and the table is set to the required angle *a*, as shown by the graduations at one end. This adjustment locates the axis of the work at an angle with the table's line of motion; hence, a taper is produced, the angle of which depends upon the amount that the table is turned from its central or parallel position. There are usually two sets of graduations for the swivel-table, one reading to degrees and the other giving the taper in inches per foot. The taper should be tested before the part is ground to the finished size by using a gage, or in any other available way.

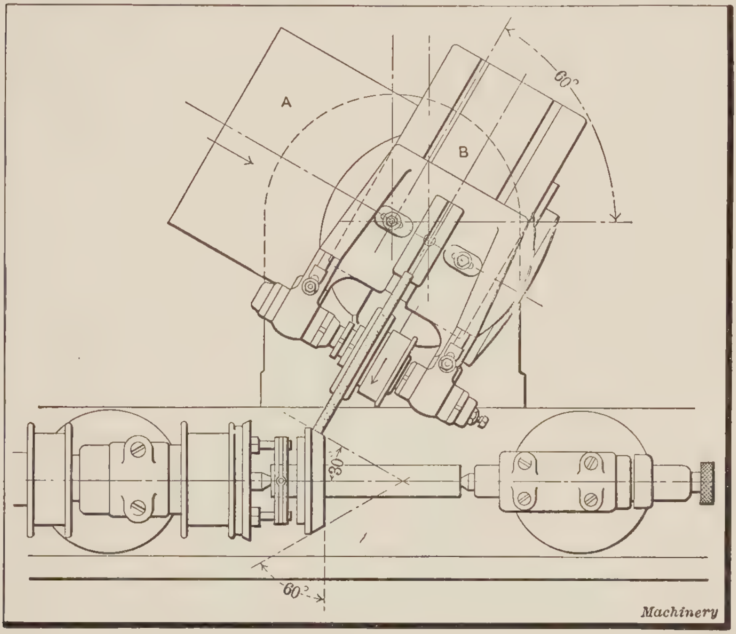


Fig. 37. Grinding Abrupt Taper by setting Wheel Slide of Universal Machine to Required Angle

The plan view, Fig. 37, shows how a taper surface is ground when the angle is beyond the range of the swivel-table. The wheel slide *A* (which is normally at right angles to the table) is set to bring its line of motion parallel with the taper to be ground. The upper wheel-stand *B* is also set at right angles to slide *A*, to locate the wheel-face parallel with the taper surface. The table of the machine should be set in the zero position, so that the angular graduations on the wheel-slide base will give correct readings with relation to the axis of the work. After adjusting the table to the proper longitudinal position, the grinding is done by moving the wheel across the taper surface by using the hand cross feed, and the depth of each cut is regulated by slight longitudinal adjustments of the table. When the taper is tested, if any adjustment is necessary, this can be made by the table adjusting screw. Evidently an operation of this kind must be done on a universal machine, because the wheel slide of a plain type does not have the angular adjustment.

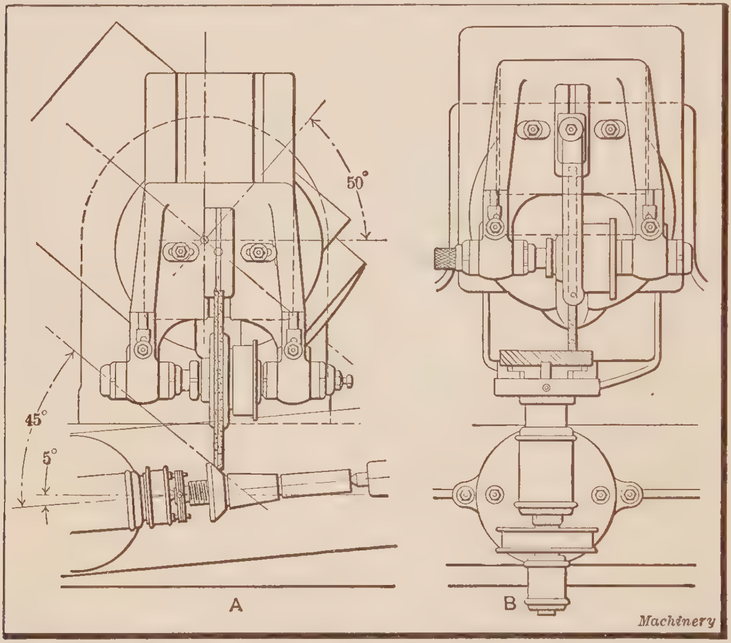


Fig. 38. (A) Grinding a Double Taper by Traversing both Platen and Wheel Slide Successively. (B) Grinding Side of a Disk on Universal Machine

Parts having a double or compound taper can be ground at one setting, provided one taper is within the range of the swivel-table. The latter is set for the smaller angle and the wheel slide for the greater angle, as indicated by the sketch *A*, Fig. 38. The wheel is set at right angles to the longest surface and one corner is beveled to suit the other surface. One part is then ground by traversing the table and the other by moving the wheel slide. The wheel-base, in this instance, should be set to an angle corresponding to the sum of the angles of both tapers, as measured from the axis. The sum of both angles, in the example illustrated, is 50 degrees.

Use of the Universal Head. — The headstock of the universal grinder is used for holding and revolving many parts, such as saws, milling cutters, and other pieces that cannot be revolved between the centers. Sometimes the work is held in an ordinary chuck screwed to the headstock spindle, and special collet chucks or fixtures are also employed, as well as magnetic chucks, where electric power is available. Sketch *B*, Fig. 38, illustrates how the side of a plain, flat disk is ground. The headstock spindle is set at right angles to the table, and the work, in this case, is held in a four-jawed chuck. When grinding, the wheel operates on only one side of the disk, and the automatic table traverse is used. If the surface must be flat, it can be tested with a straightedge or

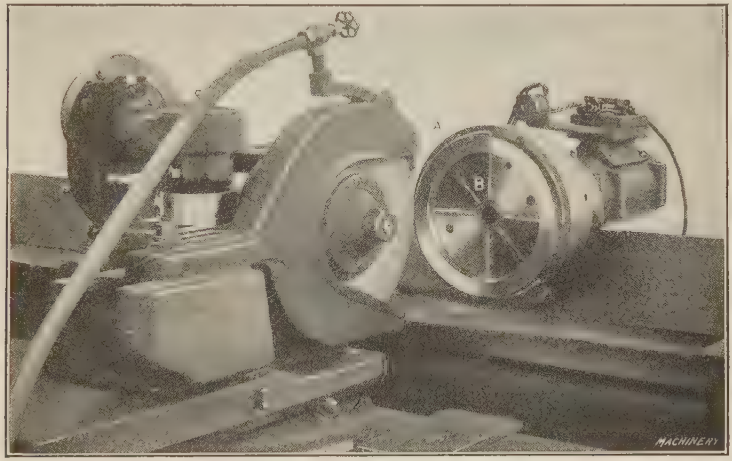


Fig. 39. Grinding Side of Steel Ring which is held by a Rotary Magnetic Chuck

by allowing the wheel to pass clear across the face and noting the density of the sparks on both sides. When the sparks show the same at all points, the surface is flat within close limits. The fine adjusting screw for the table should be used for making adjustments. Obviously, concave or convex surfaces can be ground by setting the headstock to the required angle.

Fig. 39 illustrates the use of a magnetic chuck attachment for face grinding. The operation is that of grinding the sides of a steel ring *A*. As these sides must be flat, the headstock spindle is set at right angles to the wheel-spindle. The work is rotated by a belt (not in place) which passes over a pulley located just back of the magnetic chuck *B*. The current for magnetizing the chuck is conveyed through the wires and brushes shown. The wheels used for grinding flat surfaces should be of a softer grade than for cylindrical work, owing to the greater contact area.

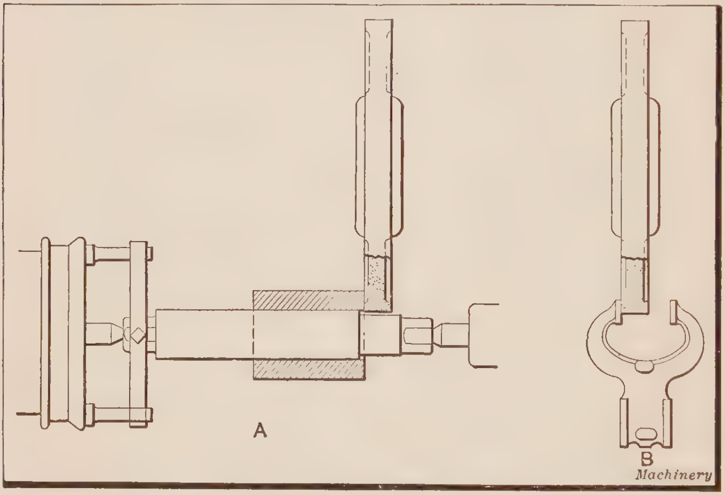


Fig. 40. Grinding with the Side of a Recessed Wheel

Grinding with Side of Wheel. – When it is necessary to grind bushings or sleeves, they are sometimes mounted on a mandrel, as shown at *A*, Fig. 40. This view illustrates how the end of a bushing is finished by grinding with the side of the wheel. A wheel for end facing should be soft and porous and it should also be recessed on the sides (as shown by the sectional view) to reduce the working area. The grinding should be done by moving the work endwise against the side of the wheel, instead of traversing the wheel laterally. This method of facing the ends of cylindrical parts is only employed when the surfaces are quite narrow. Diagram *B* indicates how the jaws of a caliper gage are ground by the side of the wheel. The gage is held in a fixture attached to the table of the machine and the wheel is traversed across the face of the jaw being ground. It is necessary to traverse the wheel in this instance because the work is not revolving.

Truing Grinding Machine Centers. — Fig. 41 illustrates how a universal grinding machine is used to true its own centers. The headstock is set to an angle of 30 degrees, giving an included standard angle of 60 degrees, and the grinding is done by traversing the wheel across the conical surface. The tailstock center is ground, first, by inserting it in the headstock spindle, these centers being interchangeable. The table stroke should be adjusted so that the wheel overlaps the taper surface slightly on each side, and a copious supply of water should be used, when grinding, to prevent drawing the temper of the hardened centers. The centers of a plain grinder are inserted in a special fixture while being trued. This fixture is clamped to the table and holds the center at an angle of 30 degrees. It is very important to keep the centers in good condition, as, otherwise, parts ground upon them will not be accurate.

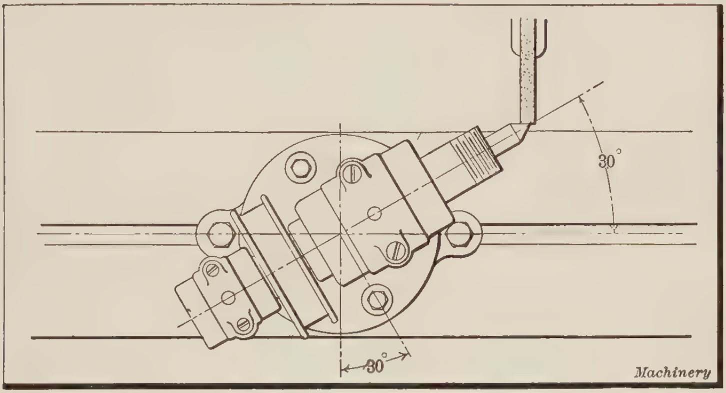


Fig. 41. Truing Conical Center of a Universal Grinding Machine

Roll-grinding Machine. — The cylindrical grinding machine is adapted to the finishing of rolls such as are used for rolling steel plate, etc. Rolls of the smaller sizes are often ground on ordinary cylindrical grinders, but where roll grinding is done regularly, especially on rolls of large sizes, machines designed for this work are used. Front and rear views, showing part of a large Norton machine intended for the grinding of rolls used in rolling steel plate, are shown in Figs. 42 and 43. This machine will grind rolls 54 inches in diameter and 18 feet long.

Years ago, Mr. J. Morton Poole invented the double-wheel machine with a swinging frame to secure accurate cylindrical work, because, at that time, there were no known methods of producing and maintaining straight ways of sufficient accuracy to secure perfectly straight lines or a uniform diameter of roll with a single grinding wheel. By means of modern methods, however, it is practicable to produce and maintain ways for a single grinding wheel which will produce rolls that are practically perfect. Incidentally, the advantage of this single wheel is that with the present design it is possible to have the wheel large in diameter, of wide face, and so mounted and provided with a powerful drive that it is possible to grind rolls in a few hours, which formerly required a day or more for their grinding. It is also more convenient to place heavy rolls in the machine, or

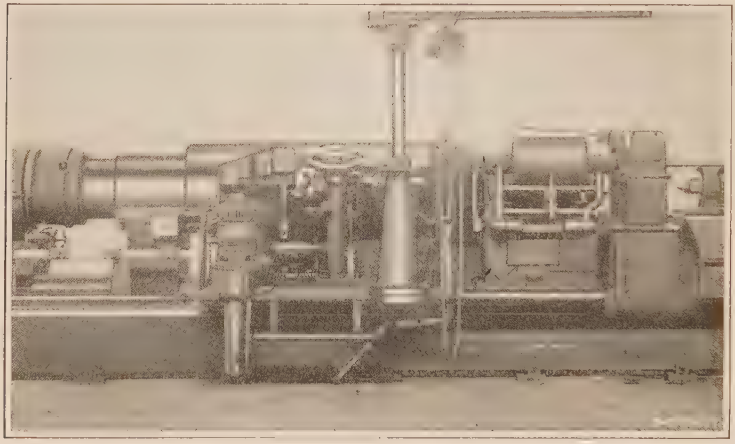


Fig. 42. Partial Front View of Norton Roll-grinding Machine

remove them from the machine, than when the double-wheel machine is used.

Under the old system, a roughing cut was unknown. All cuts were practically finishing cuts, and hours, in fact, days, were spent in the slow process of grinding with small wheels not exceeding 14 or 15 inches in diameter by 1 or 2 inches in width, and relatively small spindles and frail supports were provided for carrying these wheels. With the single-wheel machine of modern design, advantage can be taken of greater weight and power, securing accuracy, and, at the same time, large production.

The work to be ground is of such size, that, in order to see the point of contact between the work and the grinding wheel, it is necessary for the operator to have control of the machine on the same side of the work as the wheel is grinding. To secure perfectly smooth work, the rolls are revolved through helical gears and a large worm and worm-wheel running in a bath of oil, six speeds of work revolution being provided.

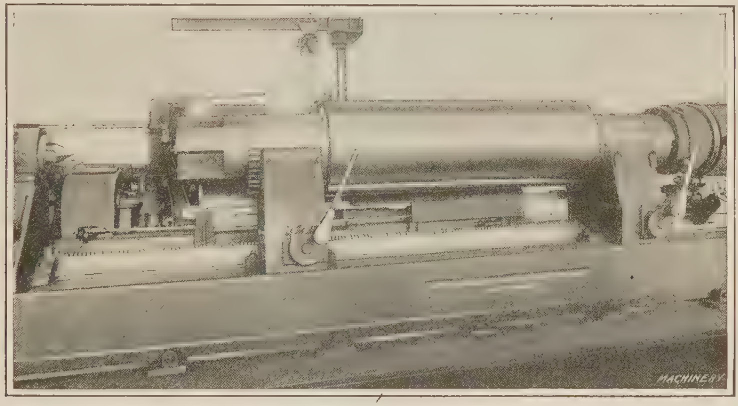


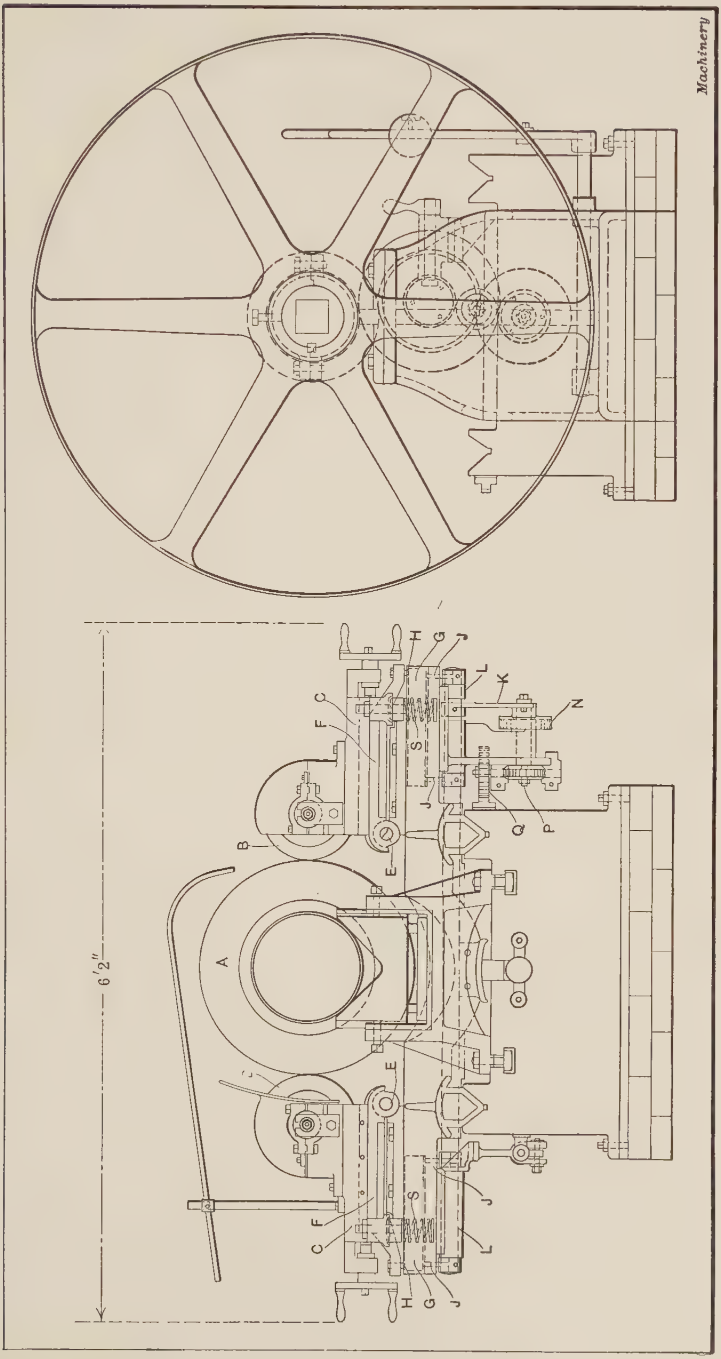
Fig. 43. Rear View of Norton Roll Grinder showing how Roll is Supported while being Ground

When grinding rolls carried on their own bearings, they are revolved by means of a large universal joint, in order to give a steady and uniform rotation of the work, one end of the universal joint being bolted to the faceplate of the headstock spindle. To the other end is bolted a driving sleeve which clamps solidly to the wabbler end of the roll, revolving as a part of the roll. When grinding work on centers, the universal joint, the universal joint case, and the driving sleeve are removed and a driver is bolted direct to the faceplate on the headstock spindle. Provision is made for grinding the necks of the rolls, either when carried on the machine centers or when the rolls are revolved upon their necks in specially arranged bearings. When desired, an attachment can be supplied for this machine, which will permit grinding rolls with either a concave or convex face. The machine, as shown in the illustrations, is arranged for grinding rolls either cylindrical or with straight tapers, whether or not the rolls are carried on centers when being ground.

Calender Roll Grinding. — Calender rolls are used in connection with the manufacture of paper to produce a uniform thickness, hardness, and a good surface finish. The great size and weight of the calender rolls, of which there may be two or three stacks, are astonishing to one unfamiliar with paper making. Rolls 200 inches long and 30 inches in diameter have been made for some of the largest paper-making machines. Now, when it is taken into account that these rolls must be extremely hard, perfectly round, and highly polished, the problem of production seems sufficiently difficult, but when, in addition, it is considered that the bottom and top rolls have to be ground large in the middle, tapering to the ends, in order to compensate for deflection, the problem becomes still more difficult.

The Lobdell roll-grinding machine of the electrically-driven type, made by the Lobdell Car Wheel Co., Wilmington, Del., is shown in Figs. 44 and 45. The rolls are supported on their journals by V-blocks which are adjustable on the bed for various lengths. The V-blocks have been found best for this work, inasmuch as the journal automatically centers itself and requires no lateral adjustment. Two grinding wheels are provided, one on each side of the roll. The wheels are each driven by two belts. The spindle bearings are a plain taper and are supported in phosphor-bronze bearings.

Calender rolls must be ground with great accuracy and to the utmost smoothness; the metal is dense chilled cast iron. The grinding wheels are mounted on a carriage, and, in the case of the motor-driven machine, the carriage also carries the motors over-



Machinery

Fig. 44. End Views of Lobdell Roll-grinding Machine showing Carriage Construction and Driving Mechanism for Roll and Carriage

head. In the case of the belt-driven machines, two overhead drums are provided of a length equal to the longest traverse required. As the grinding wheels are mounted on opposite sides of the roll, the thrusts of the wheels against the roll are balanced. The wheels are comparatively narrow, the usual width being about 1½ inch, and the feed of the carriage is somewhat less than the wheel width, as is usual in all cylindrical grinding operations. The roll is flooded during grinding.

A stack of calender rolls is erected so that the entire weight is carried on the bottom roll. Besides this, additional load is imposed by weights acting through a system of multiplying levers. The effect of the superimposed load, which may amount to 50,000 pounds, is to deflect both the top and the bottom rolls an appreciable amount. To compensate for this deflection, both the top and the bottom rolls must be ground with a "crown," that is, larger in the center than at the ends. The amount of crown varies with the diameter and length of roll, being 0.010 inch in the case of 16-inch rolls, 116 inches long.

It is evident that an ordinary former or guide for producing the crown is open to several objections. The crown is so small that it would be difficult to make a long guide with the required amount accurately apportioned to each foot of its length. The crown being so small, the wear of the guide shoes and deflections would tend to destroy its accuracy. Another objection is that either a large number of formers or guides must be provided or means for changing the shape of the guide by set-screws. The latter are objectionable because of the practical impossibility of making the crown uniform. When these difficulties are understood, the fine points of the crowning device to be described will be better appreciated.

The roll *A* is mounted by the ends in V-blocks and is ground by the opposite wheels *B*. The wheels are given a slight in-and-out movement for "crowning" the roll, the movement being controlled by the mechanism about to be described. The rack *R* is bolted to the front of the bed and engages with a pinion *Q*. This pinion carries a worm which drives a worm-wheel, which, in turn, rotates crank *N*; the latter has an adjustable crankpin

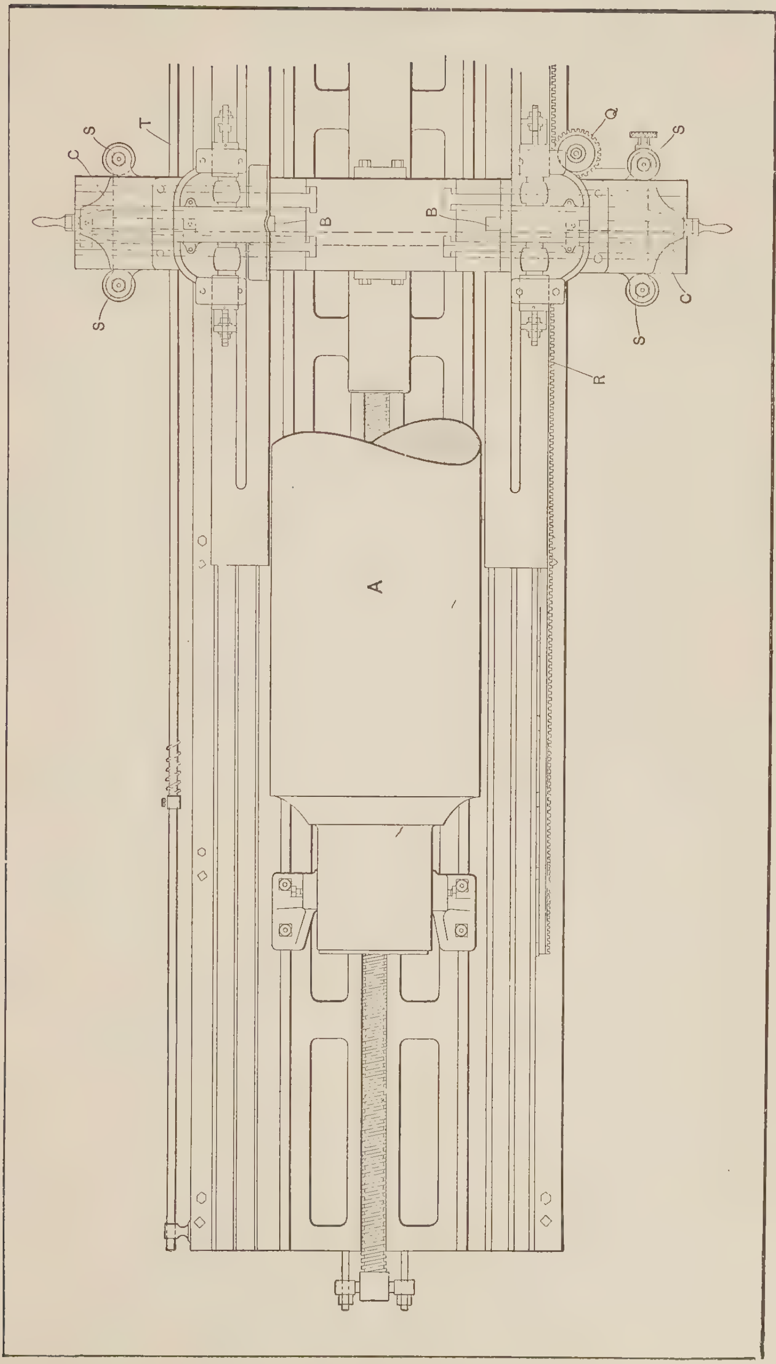


Fig. 45. Plan View of Lobdell Roll-grinding Machine

that is connected to the lever *K* by a connecting-rod. The lever *K* is mounted on a transverse shaft *L* extending across the bed under the carriage bridge. At each end are two short horizontal levers mounted on *L* on which rest vertical pins *J*, which, in turn support a bar *G*.

The function of this train of mechanism is to raise and lower the grinding wheel heads on the pivots *E* and to provide means for making the angular movement the same for a given adjustment for any diameter of roll within the capacity of the machine. The point of contact between the bars *G* and the grinding wheel cross-slide heads is at *H*. It is evident that the rise and fall will be the same for a given adjustment no matter at what point *H* contacts with *G*. The wheel slides have two lateral adjustments; one is by means of the screw and handle which moves the top slide on which the wheel is mounted. Then there is a lower slide, the base of which is bolted to the carriage, and is provided with T-slots for changing the position laterally. The springs *S* are provided to take up the slack in the mechanism and insure the movement of the wheels in the crowning operation, following exactly the curve determined by the design of the mechanism.

The operator is provided with a table of roll lengths, diameters, crowns, and crankpin adjustments, from which he can read the adjustment necessary to control the position of the crankpin on worm-wheel *N*. The amount of calender or crown has been carefully determined for all lengths and diameters of calender rolls within commercial limits. For example, 0.010-inch crown is given to a 16-inch roll, 116 inches long. The adjustment required for the crankpin is 0.339 inch eccentricity, that is, it is set to swing in a circle of 0.678 inch diameter. The crown produced is a true arc of a circle in the direction of its length.

The carriage is traversed by a feed-screw which bears throughout its entire length in a groove in the bed. The groove is planed accurately to shape, in order to form a solid support throughout the length. A half-nut of phosphor-bronze is engaged with the screw. The screw is reversed at the end of the travel by a feed-rod *T* having adjustable collars which shift the reversing gears into engagement.

CHAPTER II

FORM GRINDING

The grinding of machine parts by using a broad wheel which is shaped to conform to the shape required, and without traversing either wheel or work laterally, is known as form grinding. The wheel is wide enough to cover the surface to be ground, and, for round work, is fed straight in, thus grinding the entire surface at the same time, without a traversing movement such as is common to ordinary cylindrical grinding. Form grinding bears practically the same relation to grinding by means of a traversing wheel, as forming tools do to the ordinary single-point turning tool. In the case of forming tools, however, the sharpening is done on the flat face of the tool and the formed surface is not changed throughout the life of the tool, whereas, with a form grinding wheel, the sharpening is done on the formed surface which may be either straight, curved, or irregular. For ordinary shapes, this truing of the wheel is done without difficulty, and simply requires a special truing fixture which serves to guide the forming tool mechanically. Form grinding wheels do not require truing as often as might be supposed and a large number of pieces can be ground with one truing of the wheel.

Practically the only factors which limit the use of extremely wide wheels for form grinding are the difficulties connected with the production of wide wheels and the limitations as to the rigidity and wearing qualities of the wheel-spindle and work supports. Great progress, however, has been made in overcoming these difficulties, and the result is that considerable work is now done by form grinding that was not possible a few years ago. Obviously, the form grinding process is very efficient for classes of work to which it may be applied.

The term form grinding, as applied to the manufacture of machine and automobile parts, is generally used to refer to the production of both straight and irregular-shaped surfaces. For round work, the term is used to indicate that the wheel is fed straight in without any traverse of the wheel or work. In order to differentiate between form grinding of straight and irregular surfaces, other names for the grinding of plain surfaces have been suggested, such as straight-in grinding, wide-wheel grinding, etc. In practice, however, the term "form grinding" is used to indicate the production of both straight and irregular-shaped surfaces on cylindrical work where the work or wheel is not traversed. There are also many other applications of the formed-wheel method of grinding, such as surface grinding, grinding splined shafts, crankshafts, etc.

Form grinding first came into prominent use in the grinding of multiple-throw crankshafts for automobile engines. The chief reason for using a wide wheel and feeding it straight in on the work in the grinding of crankshafts was that the length of the bearings and space between the crankpin cheeks was so short that a very limited traverse could be used. This made the operation of grinding crankpins and bearings both slow and expensive. Heavy, rigid grinding machines were then built to carry wide face wheels, and instead of using the grinding machine for finishing only, crankshafts were ground complete on the bearings and crankpins from the rough forgings.

Advantages and Limitations of Form Grinding. — There are many advantages of form grinding, among which might be mentioned: First, greater-production; second, accurately finishing hardened parts of irregular shape; third, grinding from the rough; fourth, increasing possibilities of securing interchangeable parts. Greater production is possible because a wheel is used that covers the entire surface to be ground.

The use of form wheels presents the only practical means of accurately finishing flat or round parts of irregular form, and this advantage alone is of considerable importance. Another advantage of form grinding is in the possibility of producing interchangeable parts. With a wide face wheel, that is kept in good condition by being trued frequently with a diamond, it is a comparatively easy task to secure accurate work.

The width of face of grinding wheels used for form grinding has gradually increased, until, at present, wheels up to 10 and 12 inches face are used with success. The chief limitations of form grinding are the difficulties encountered in making the grinding wheel and in producing a machine of the necessary strength and rigidity. Another limitation is in the depth of the formed part. This can be such that the peripheral speed of the various diameters on the wheel produces a different cutting action, making the production of very deep forms impracticable. A difference of 2 inches on the diameter of the wheel, however, easily comes within the possibilities of the grain and grade that can be furnished by the wheel manufacturers. Again, wheels for form grinding must be trued up more frequently than is necessary in traverse grinding, but this is not a serious disadvantage. In fact, grinding authorities state, that, on work which must be held within close limits, a generous use of the diamond not only increases production but also insures greater accuracy of product.

Work Speeds for Form Grinding. — For form grinding soft steel, containing from 0.15 to 0.25 per cent carbon, the work speed should be in the neighborhood of from 30 to 55 feet surface speed, and is dependent upon the wheel used, and, to a certain extent, upon the finish desired. The harder the bond of the wheel, as a rule, the higher the work speed, and the softer the bond, the lower the work speed. For form grinding 0.15 to 0.25 per cent carbon steel which has been casehardened, the work speeds are just about the same as for soft steel, but the wheels are generally of a harder bond and slightly finer grain than those used for soft steel. The examples shown in the following can be used as a general guide for the selection of the proper wheels and work speeds for different classes of work.

In the grinding of alloy steels which have been heat-treated, the work speeds seldom exceed 55 feet surface speed. As a general rule, grinding wheels of combination grain are used for form grinding alloy steels, and it has been found that wheels of, say, No. 24 combination work best at surface speeds ranging from 25 to 40 feet. The harder the bond of the wheel, of course, the higher must be the surface speed to get the same results, but on form grinding, hard bond wheels of fine grain are not recommended because of the liability to glaze and heat up quickly. The speed of the work is dependent, to a certain extent, upon its diameter, small-diameter work being rotated at a higher surface speed than large-diameter work.

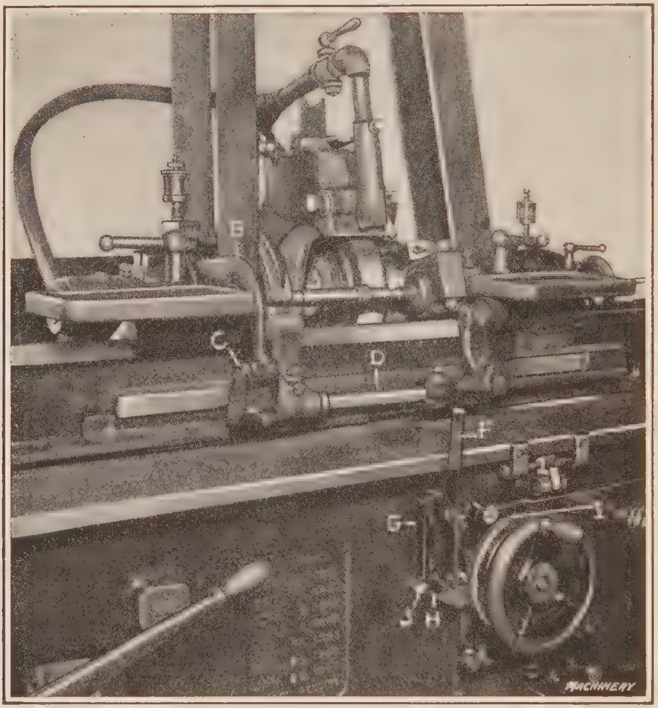


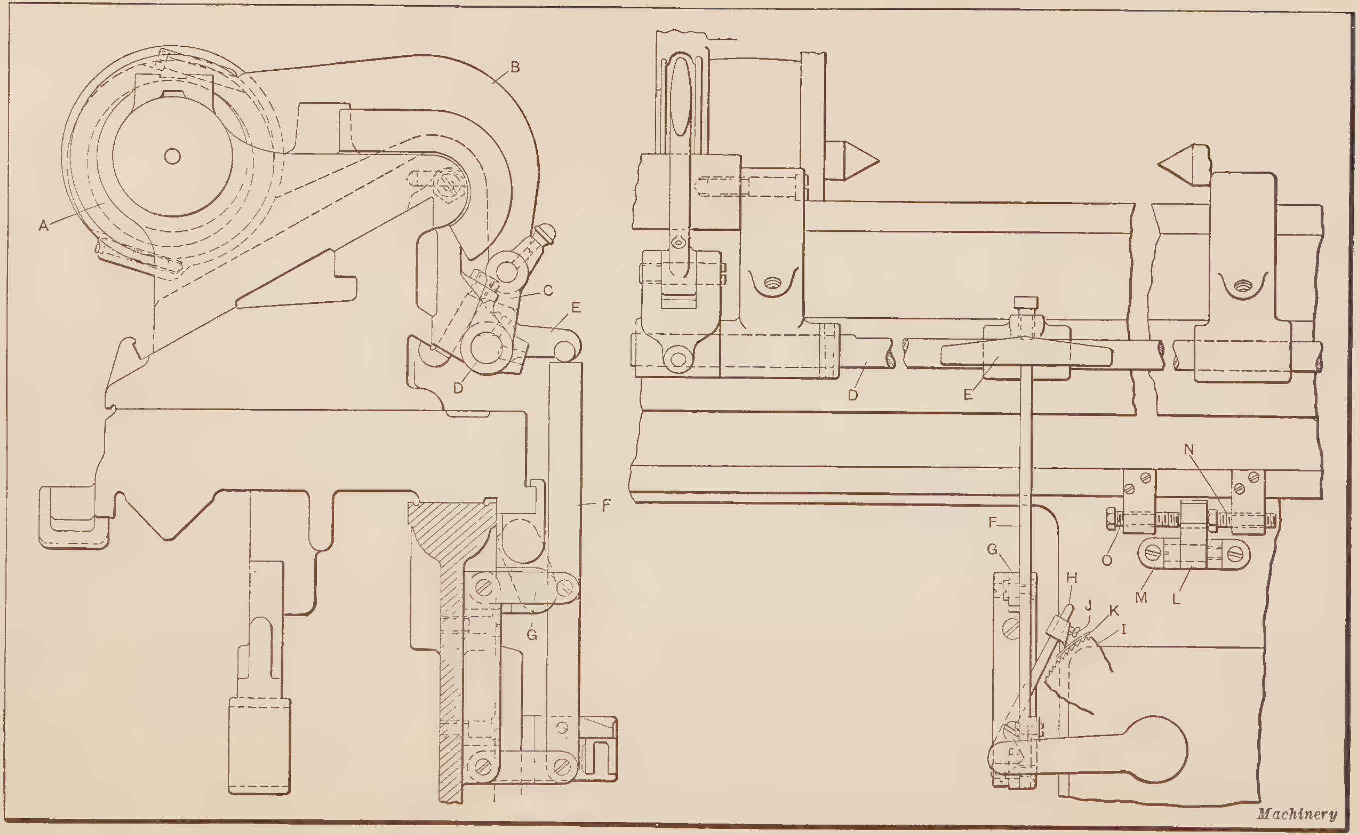
Fig. 1. Brown & Sharpe Plain Grinding Machine equipped with Special Automatic In-feeding Mechanism for Form Grinding

Rate of In-feed of Wheel for Form Grinding. — The rate at which the wheel is fed in on the work for form grinding varies all the way from 0.0005 to 0.003 inch per revolution of the work, the rate of in-feed depending on the slenderness of the work and the manner in which it is supported, also, to some extent, on the rigidity of the machine in which the operation is being done. This in-feeding of the wheel on the work is generally done by hand, but several devices have been designed for doing this by power. Of course, the hand-feed method offers more latitude, as far as increasing production is concerned, than the power feed, but can only be done successfully by an experienced operator.

An interesting in-feeding device, which has been applied to the Brown & Sharpe plain grinding machine for form grinding, is shown in Figs. 1 and 2. This device is operated as follows: An eccentric *A* on the headstock spindle oscillates a shaft *D* through lever *B* and connection *C*. Shaft *D* carries an adjustable shoe *E* which can be moved along it to contact with lever *F*. This lever is fulcrumed in bracket *G* and on its lower end carries a ratchet pawl lever *H*. Ratchet pawl *H*, in turn, carries a pawl *J*, which engages with a feeding dial *I* fastened to the same shaft that carries the handwheel for operating the in-feed of the grinding wheel slide.

As the work head revolves, pawl *J* moves the feeding dial *I* around two notches, or, in other words, brings the grinding wheel in at the rate of 0.002 inch per revolution of the work. This continues until the correct diameter has been reached, when the automatic trip comes into play. This consists of a segment shield *K* fastened to the feeding dial and adjustable around its circumference. This, as shown in Fig. 2, passes beneath the pawl, raising it and preventing any further action upon the ratchet dial. The grinding wheel is then allowed to dwell on the work until no sparks show, and, in this way, very accurate dimensions can be obtained. In fact, the limits on the particular piece on which this device was used were 0.0005 inch on the diameter. Feeding the wheel in on the work by power feed has an advantage over the hand feed, inasmuch as no feeding is done if the belt driving the work-spindle slips. When an operator is feeding the wheel in by hand, care must be taken to see that the work runs smoothly, or else flats will be produced on the work. Of course, if the wheel is allowed to dwell at the end of the cut, these flats will be eliminated in most cases.

Multiple Diameter Grinding. — When a cylindrical part has a number of different diameters, these may be finished simultaneously by form grinding, provided the sum of the lengths of all the surfaces does not exceed the width of the widest wheel



Machinery

Fig. 2. Detailed View of Automatic Feeding Mechanism used on Machine shown in Fig. 1

which can be used on the machine. The procedure is to form as many diameters on the wheel as are required on the work, there being corresponding differences in the radii; the work is then ground by feeding the wheel straight in, the same as for any form grinding operation. If there is little difference between the various diameters, it is not economical to rough-turn them in the lathe, the method being to simply rough-turn a cylindrical piece slightly larger than the largest size and allow the grinding wheel to grind away the smaller portions. While this method makes it necessary to true the wheel oftener, it is usually cheaper than attempting to rough-turn each size, provided the diameter differences are small, as previously mentioned.

The length of the different surfaces may be such that it is not practicable to grind them simultaneously by using a form wheel, and a plain wheel, that grinds each diameter independently, must be employed. In order to facilitate work of this kind, the Norton Grinding Co. designed a device for positively and accurately locating a plain wheel in two or more positions for grinding different diameters. Incidentally, this same locating device can be used for setting the grinding wheel when truing its face for different diameters preparatory to form grinding. This locating attachment (which is shown in Fig. 7, Chapter VIII) is composed of a ring that is attached to the regular index-crank or handwheel by means of which the movement of the wheel slide is controlled. On the periphery of this ring there is a dovetail slot in which any desired number of stop-blocks may be fastened. These blocks are engaged by a pivoted stop-arm, and, by adjusting them in different positions, the grinding wheel may be accurately located. For instance, when grinding a part having three diameters, three blocks would be attached to the ring in positions that would locate the wheel for grinding exactly the right diameters in each case. After grinding one size, the handwheel would be moved until the stop-arm made contact with the next block; the grinding wheel would be located in a similar manner for finishing the third diameter. After the blocks are once set, obviously, they form a convenient means for setting the machine when grinding duplicate parts.

If, instead of grinding with a plain wheel, the object were to produce two different diameters on the wheel for form grinding, the procedure would be somewhat different. First the wheel would be trued straight across the face with the first block against the stop-arm. Then the handwheel would be turned until the second block engaged the stop-arm, thus advancing the grinding wheel towards the diamond an amount depending upon the distance between the blocks. A certain part of the wheel-face would be then trued to this smaller size.

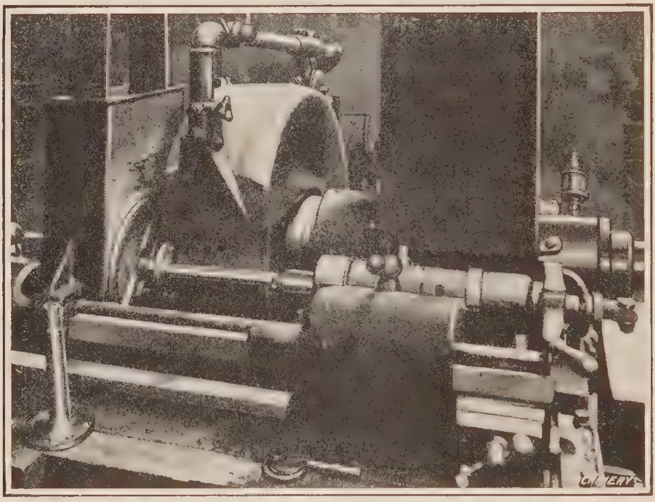
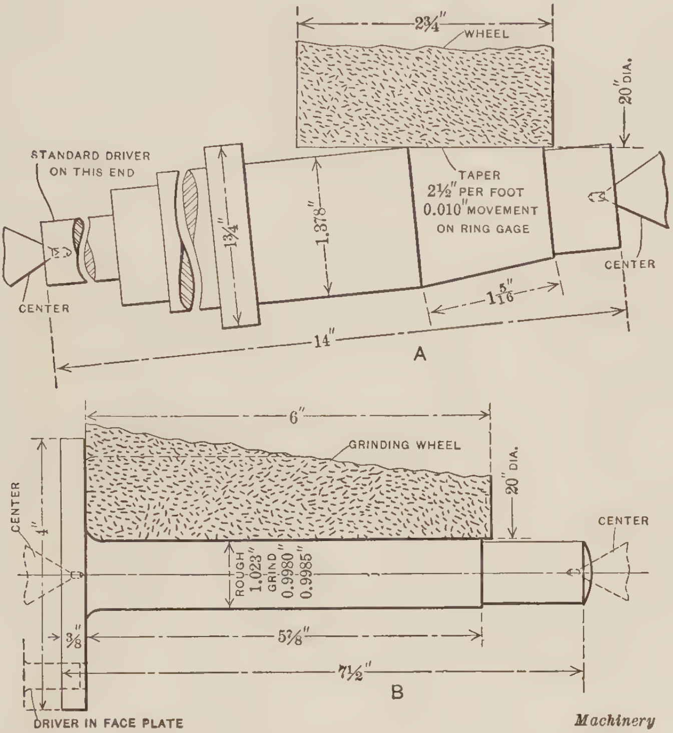


Fig. 3. "Special-purpose" Norton Plain Grinding Machine arranged for Form Grinding an Automobile Transmission Shaft

Form Grinding Transmission Shafts. — The finishing of transmission shafts for automobiles is a good example of the advantages to be gained by the use of wide wheels fed straight in on the work. Fig. 3 illustrates a "special-purpose" Norton plain grinding machine set up for this work in the plant of the Ford Motor Co. This shaft is brought directly from the lathe turning operation and is finished complete at the rate of 550 in eight hours to limits of 0.0005 inch on the diameter. As is shown at *B*, in Fig. 4, a No. 24 and 38 combination grain alundum wheel is used for the job, the wheel being 6 inches wide and 20 inches diameter. *A*, in Fig. 4, shows a transmission main



A

Work: — Transmission main drive shaft, 0.20 per cent carbon open-hearth steel, carbonized and hardened.

Operation: — Straight-in grinding taper with a Norton (vitrified) alundum combination wheel, grain 38–24, grade L; 20 inches diameter, 2¾ inch face; 1146 R.P.M. — 6000 feet surface speed; work speed, 200 R.P.M. — 70 feet average surface speed; amount removed from diameter, 0.015 to 0.025 inch.

Remarks: — Wide-face wheel is fed straight in on work, not traversed, and work-table is set off to the correct taper; production, 325 pieces in nine hours; machine used, 10 by 36 inch Norton plain grinding machine.

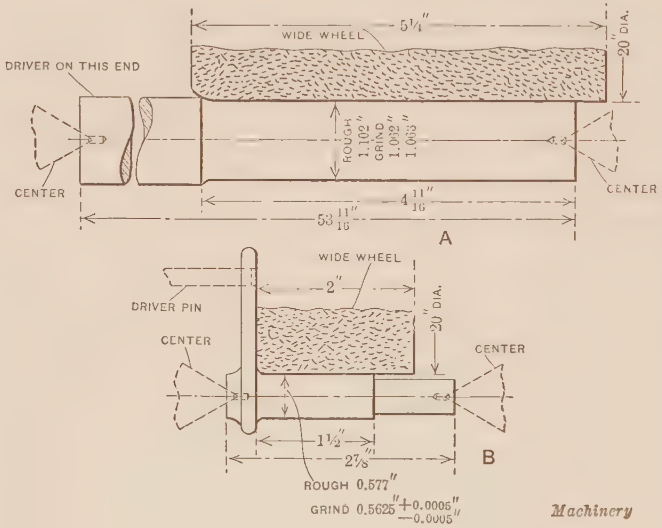
B

Work: — Transmission shaft, 0.20 to 0.25 per cent carbon, 0.018 per cent vanadium alloy steel drop-forging, heat-treated.

Operation: — Straight-in grinding shank with a Norton (vitrified) alundum combination wheel, grain 38–24, grade L; 20 inches diameter, 6 inch face; speed, 1146 R.P.M. — 6000 feet surface speed; work speed, 150 R.P.M. — 39 feet surface speed; amount removed from diameter, 0.025 inch.

Remarks: — Wide-face wheel is fed straight in on work, not traversed; 65 pieces turned out to each truing of wheel; production, 550 pieces in eight hours; machine used, 10 by 24 inch Norton special-purpose plain grinding machine.

Fig. 4. Form Grinding Operations on Automobile Transmission Shafts



A

Work: — Automobile drive shaft, 0.20 per cent carbon, chrome-nickel vanadium, hot-rolled steel bar, heat-treated.

Operation: — Straight-in grinding plain bearing with a Norton (vitrified) alundum combination wheel, grain 38–24, grade L; 20 inches diameter, 5¼ inch face; 1146 R.P.M.— 6000 feet surface speed; work speed, 200 R.P.M. — 55 feet surface speed; amount removed from diameter, 0.030 to 0.040 inch.

Remarks: — Wide-face wheel is fed straight in on work, not traversed; 60 pieces turned out to each truing of wheel; production, 375 pieces in eight hours; machine used, 10 by 50 inch, Norton special-purpose plain grinding machine.

B

Work: — Automobile spring shackle, 0.20 per cent carbon, 0.18 per cent vanadium drop-forging, heat-treated.

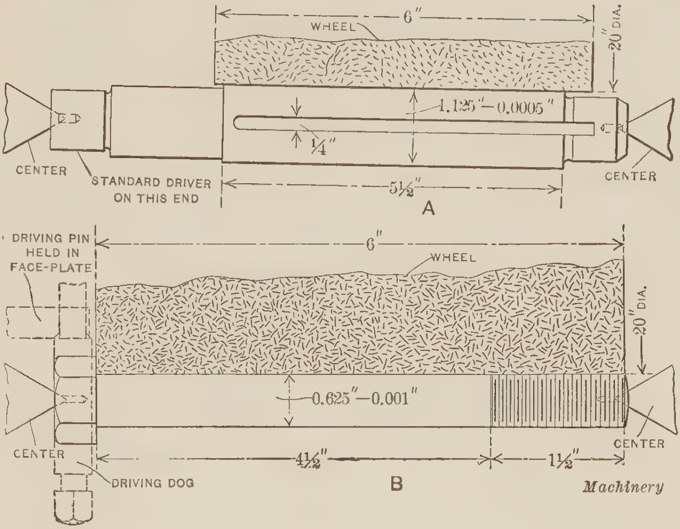
Operation: — Straight-in grinding shank with a Norton (vitrified) alundum wheel, grain 46, grade O; 20 inches diameter, 2 inch face; 1146 R.P.M. — 6000 feet surface speed; work speed, 480 R.P.M. — 71 feet surface speed; amount removed from diameter, 0.012 to 0.015 inch.

Remarks: — Wide-face wheel is fed straight in on work, not traversed; 22 pieces turned out to each truing of wheel; production, 1400 pieces in eight hours; machine used 6 by 32 inch Norton plain grinding machine.

Fig. 5. (A) Automobile Drive Shaft. (B) Automobile Spring Shackle

drive shaft on which a taper bearing is being ground. In this case, the same grain and grade of wheel is used, but the work speed is much higher.

The automobile drive shaft shown at *A*, in Fig. 5, is another good example of "straight-in" grinding. In this case, a wheel 5¼ inches wide is used and the work is finished to a limit of 0.001 inch on the diameter. The same grade and grain of wheel is



A

Work: — Transmission countershaft, 0.20 per cent carbon open-hearth steel, carbonized and hardened.

Operation: —Straight-in grinding external diameter with a Norton (vitrified) alundum combination wheel, grain 38–24, grade L; 20 inches diameter, 6 inch face; speed, 1241 R.P.M. — 6500 feet surface speed; work speed, 100 R.P.M. — 30 feet surface speed; amount removed from diameter, 0.015 to 0.025 inch.

Remarks: — Wide-face wheel is fed straight in on work, not traversed; 50 pieces turned out to each truing of wheel; production, 330 pieces in nine hours; machine used, 10 by 36 inch Norton plain grinding machine.

B

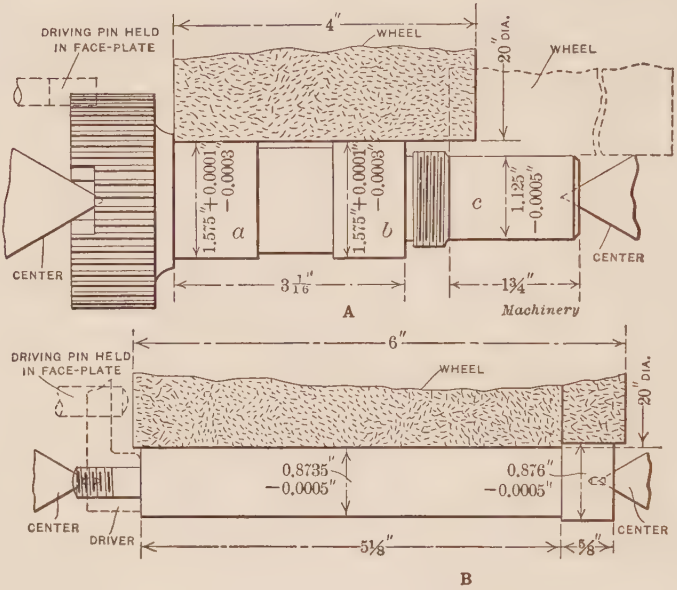
Work: — Front axle spindle bolt, 0.20 per cent carbon open-hearth steel, carbonized and hardened.

Operation: — Straight-in grinding external plain surface and threaded section with a Norton (vitrified) alundum combination wheel, grain 38-24, grade L; 20 inches diameter, 6 inch face; speed, 1241 R.P.M. — 6500 feet surface speed; work speed, 200 R.P.M. — 33 feet surface speed; amount removed from diameter, 0.015 to 0.025 inch.

Remarks: — Wide-face wheel is fed straight in on work, not traversed; 50 pieces turned out to each truing of wheel; production, 480 pieces in nine hours; machine used, 10 by 36 inch Norton plain grinding machine.

Fig. 6. Form-wheel Method applied to Automobile Transmission Countershaft and Front Axle Spindle Bolt

used as for the parts shown in Fig. 4, but the work speed has been slightly increased over the example shown at *B*. This increase in speed, however, is not beyond the limits of the grain and grade of the wheel used. The automobile spring shackle shown at *B*, in Fig. 5, illustrates one point previously stated regarding the work speed. In this case, it will be noticed that an alundum wheel, grain 46, grade O, is used, and the surface



A

Work: — Main drive gear, 0.20 per cent carbon alloy steel, carbonized and heat-treated.

Operation: — Straight-in grinding external diameter with a Norton (vitrified) alundum combination wheel, grain 38–24, grade L; 20 inches diameter, 4 inch face; speed, 1241 R.P.M. — 6500 feet surface speed; work speed, about 100 R.P.M. — 41 feet surface speed; amount removed from diameter, 0.010 inch.

Remarks: — Wide-face wheel is fed straight in on portions (a) and (b), not traversed; small end (c) is also ground in same setting by shifting wheel; production, 265 pieces in nine hours; machine used, 10 by 36 inch Norton plain grinding machine.

B

Work: — Idler gear shaft, 0.20 per cent carbon open-hearth steel, carbonized and hardened.

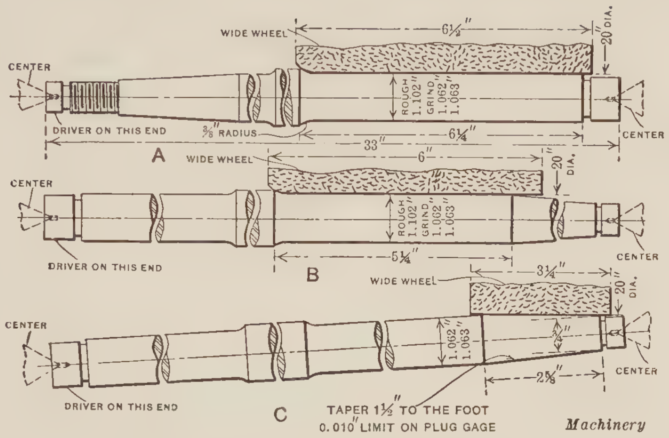
Operation: — Straight-in grinding two external diameters with a Norton (vitrified) alundum combination wheel, grain 38–24, grade L; 20 inches diameter, 6 inch face; speed, 1241 R.P.M. — 6500 feet surface speed; work speed, 100 R.P.M. — 24 feet surface speed; amount removed from diameter 0.015 to 0.025 inch.

Remarks: — Wide-face wheel is fed straight in on work, not traversed; 50 pieces turned out to each truing of wheel; production 375 pieces in nine hours, machine used, 10 by 36 inch Norton plain grinding machine.

Fig. 7. (A) Grinding Idler Gear Shaft. (B) Grinding Two Diameters with a Form Wheel

speed is 71 feet. This high speed is permissible because the grain is much finer than for example *A* and the bond harder.

Fig. 6 shows two interesting examples of form grinding. One is a transmission countershaft which is made from 0.20 per cent carbon open-hearth steel, carbonized and hardened, and the



Work: — Rear axle shaft, 0.20 per cent carbon, 0.18 per cent vanadium alloy steel bar, hot-rolled and heat-treated; allowance 0.030 to 0.040 inch left on all diameters for grinding; wheel fed straight in on work without traverse; wheel allowed to dwell at end of cut until practically no sparks show; grinding limit 0.001 inch on straight portions of shaft; three operations on a 10 by 36 inch Norton special-purpose plain grinding machine.

Operation A: — Wheel, Norton (vitrified) alundum combination, grain 38–24; grade L; 20 inches diameter, 6½ inch face; speed, 1146 R.P.M. — 6000 feet surface speed; work speed, 200 R.P.M. — 55 feet surface speed; 60 pieces turned out to each truing of wheel; production, 350 pieces in eight hours.

Operation B: — Wheel, same as above; same data also applies to wheel speed, work speed, production, etc.

Operation C: — Wheel, Norton (vitrified) alundum combination, grain 38–24, grade L; 20 inches diameter, 3¼ inch face; speed, 1146 R.P.M. — 6000 feet surface speed; work speed, 200 R.P.M. — 51 feet average surface speed; 60 pieces turned out per each truing of wheel; production, 450 pieces in eight hours.

Fig. 8. Finishing a Ford Rear Axle Shaft Complete by Form-wheel Method

other is a front axle spindle bolt made from the same material.

Grinding Automobile Gear Shafts. — Two examples of form grinding on automobile parts are shown in Fig. 7. A main drive gear shaft is illustrated at *A* on which three diameters are finished by means of feeding the wheel straight in on the work without any lateral traverse. Diameters *a* and *b* are finished at the same time, whereas diameter *c* is finished by moving the work over, thus locating the wheel in the position indicated by the dotted lines.

The idler gear shaft shown at *B* (Fig. 7) is a little more difficult to grind; it has two diameters and the difference between these two diameters is only 0.0025 inch, necessitating very careful truing of the grinding wheel. To accomplish this, the grinding machine is provided with stops, so that the wheel truing device can be brought to the proper position each time for truing the wheel. The centers in the work are also center-reamed to the same depth, so as to bring the work in the correct relation to the wheel.

Form Grinding a Rear Axle Shaft. — The rear axle shaft shown in Fig. 8 is a good example of the straight-in method of grinding. Referring to this illustration, it will be seen that three different surfaces are ground by feeding the wheel straight in on the work. For one diameter, a wheel $6\frac{1}{2}$-inch face is used, for another, a 6-inch face wheel, and for the third or tapered end, a wheel $3\frac{1}{4}$-inch face is used. On this work, Norton special-purpose plain grinding machines are used. Fig. 9 shows how the work is supported while operation *B* is being performed. Here it will be seen that a Norton rigid steadyrest, of the type shown in Fig. 10, Chapter I, is used, carrying a hardened steel work-shoe. In order to grind this bearing absolutely true, knob *A* for operating the steadyrest shoe is adjusted to spring the work against the wheel as it is being finished to the required

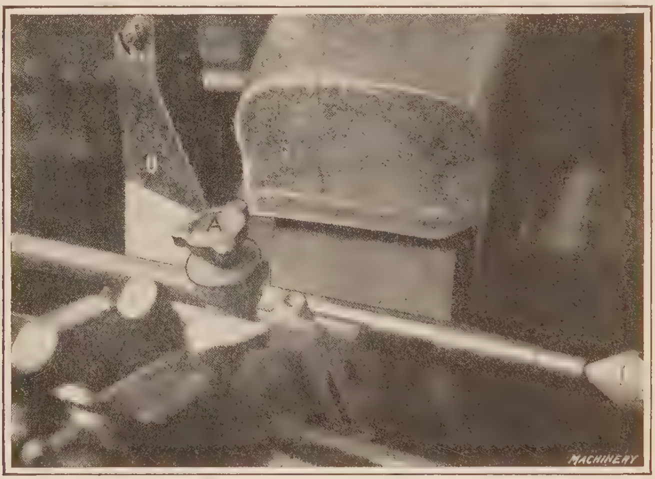
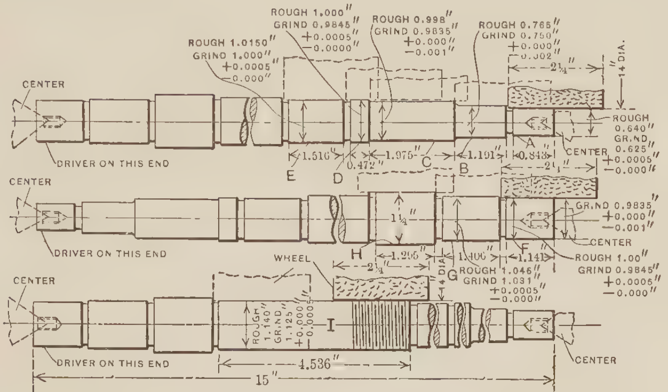


Fig. 9. Grinding a Ford Rear Axle in Norton Special-purpose Plain Grinding Machine



Machinery

Work: — Armature shaft, 0.15 to 0.25 per cent carbon machine steel; ground after rough-turning operations when soft; allowance of 0.015 inch on all diameters for grinding except one; wheel fed straight in on work without traverse at the rate of about 0.002 inch per revolution of work; wheel allowed to dwell at end of cut until no sparks show; grinding limit varies on all diameters from 0.0005 to 0.002 inch; eight form grinding operations, one traverse operation; performed on a 6 by 32 inch Norton plain grinding machine; shafts carried through in lots of 500; one shoulder finished on each shaft at one time; production, about 105 finished shafts in ten hours.

Operations A to E inclusive: — Wheel, Norton (vitrified) alundum 2¼ inches wide, 14 inches diameter; grain 24, grade N; speed, 1500 R.P.M. — 5500 feet surface speed; trued with diamond every 75 shoulders ground; work speed, 350 R.P.M. — 58 to 92 feet surface speed.

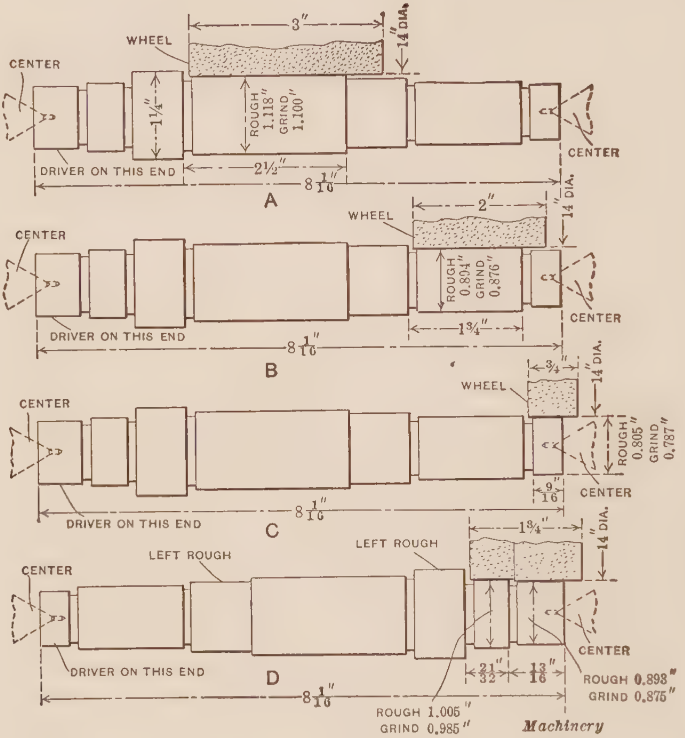
Operations F to H inclusive: — Wheel, same as above; same data also applies to wheel speed; work speed, 350 R.P.M. — 90 to 115 feet surface speed; for operation (F) wheel is trued 0.001 inch taper.

Operation I: — Wheel, same as that used for operations (A) to (H) inclusive; same data also applies to wheel speed; work speed, 350 R.P.M. — 104 feet surface speed; 0.032 inch removed from diameter; time, one minute for each shaft; wheel traversed.

Fig. 10. Motor Armature Shaft ground at the Rate of 105 in Ten Hours

diameter. Another interesting point about this job is the type of water-spout used. In this case, it will be noticed that a special water-spout made from sheet metal has been slipped over the regular spout. This spout *B* (which, in the illustration, is shown moved to one side to give a clear view of the wheel-face) is made fan-shaped and throws a stream of cutting lubricant across the entire width of face of the grinding wheel. The stream of cutting lubricant directed by this spout is also "thin," thus reducing splashing.

Grinding Motor Armature Shafts. — The motor armature shaft shown in Fig. 10 is another good example of straight-in grinding. In this case, the wheel used is not wide as compared



Work: — Electric starter shaft, cold-rolled steel; ground after rough-turning operation when soft; allowance of 0.018 inch left on all diameters for grinding; wheel fed straight in on work without traverse; in-feed, 0.002 inch per revolution of work; wheel allowed to dwell at end of cut until practically no sparks show; grinding limit, 0.00025 inch on all diameters; five operations performed on four B. & S. plain grinding machines; output, 100 shafts per hour from each machine.

Operation A: — Wheel, Norton (vitrified) alundum, 3 inches by 14 inches, combination grain 38–36, grade L; speed, 1450 R.P.M. — 5314 feet surface speed; trued with diamond for every 80 shafts ground; work speed, 188 R.P.M. — 54 feet surface speed.

Operation B: — Wheel, Norton (vitrified) alundum, 2 inches by 14 inches, combination grain 38–36, grade L; speed, 1450 R.P.M. — 5314 feet surface speed; trued with diamond after every 80 shafts ground; work speed, 188 R.P.M. — 44 feet surface speed.

Operation C: — Wheel, Norton (vitrified) alundum, ¾ by 14 inches, combination grain 38–36, grade L; speed, 1450 R.P.M. — 5314 feet surface speed; work speed, 188 R.P.M. — 40 feet surface speed.

Operation D: — Wheel, Norton (vitrified) alundum, 1¾ inch by 14 inches, combination grain 38–46, grade K; speed, 1450 R.P.M. — 5314 feet surface speed; trued after every 80 shafts with special diamond truing device carrying two diamonds; work speed, 188 R.P.M. — 43 feet average surface speed.

Fig. 11. Shaft requiring Four Form-grinding Operations

with the other examples that have been shown. This $2\frac{1}{4}$-inch face wheel, however, covers all the shoulders on the shaft except shoulder *I* which is 4.536 inches long. When grinding these shafts, one shoulder is ground at a time on about one-hundred shafts; then the operator shifts the position of the work-table in relation to the wheel and grinds the second shoulder, and so on until all the shoulders except *I* have been finished; for this shoulder the work is traversed past the wheel. Shoulder *F* is ground with a slight taper, and, for grinding this part, it is necessary to true the wheel to a corresponding taper.

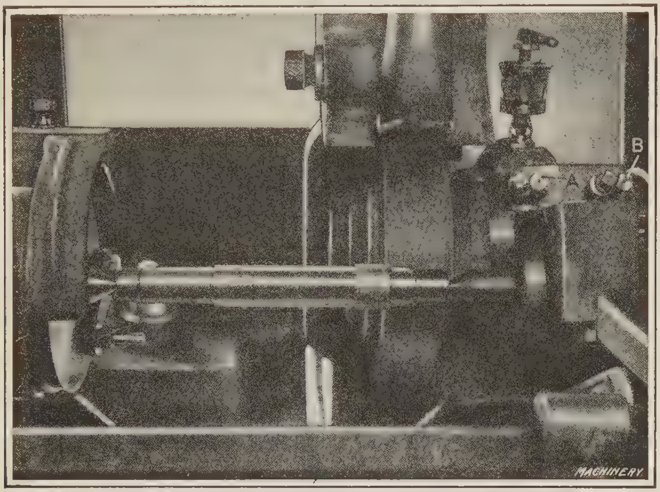
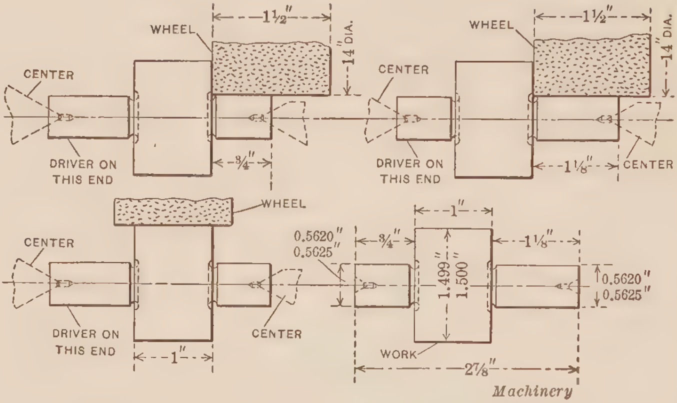


Fig. 12. Grinding Two Diameters Simultaneously on End of Shaft

Grinding Electric Starter Shafts. — The electric starter shaft shown in Fig. 11 is another example which illustrates the advantages of form grinding on shafts of the multi-shoulder variety. This particular electric starter shaft is made from cold-rolled steel and has five diameters that are ground by feeding the wheel straight in on the work. Three of the diameters require separate settings for each operation, whereas two diameters are ground by forming the wheel to cover both dimensions at the same time. In this way, five operations are performed on four machines, and the product from each machine is 100 shafts per hour. For performing operation *D*, a stop is provided on



Work: — Pump gear blank, 0.30 per cent carbon steel, not hardened.

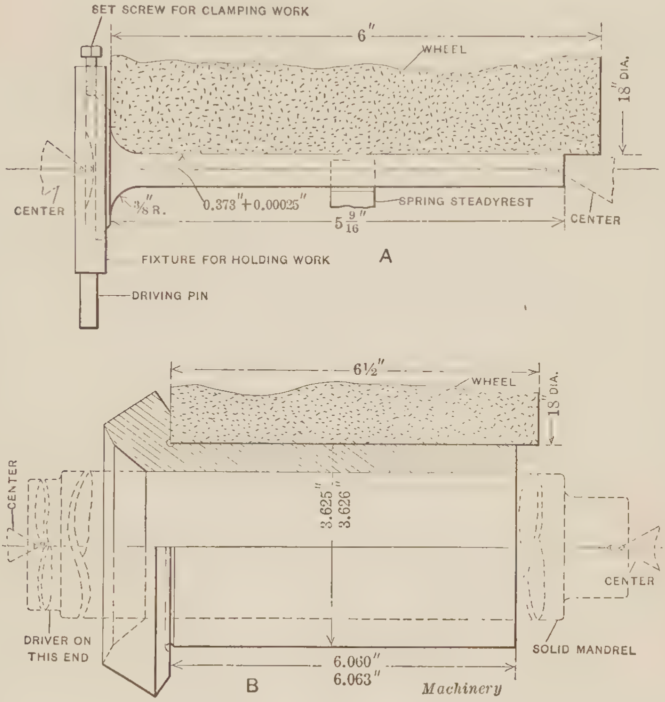
Operation: — Straight-in grinding three diameters with an American (vitrified) corundum wheel, combination grain 58–46, grade L; 14 inches diameter, 1½ inch face; speed, 1773 R.P.M. — 6500 feet surface speed; work speed, small diameters, 441 R.P.M. — 65 feet surface speed; amount removed from diameter, 0.015 inch.

Remarks: — Wide-face wheel is fed straight in on work without lateral traverse at the rate of 0.0005 inch per revolution of the work; 100 pieces turned out to each truing of wheel; work put through in lots of 100 pieces; production, 100 pieces in two hours, eighteen minutes; machine used, No. 11 Brown & Sharpe plain grinding machine.

Fig. 13. Example of Work for which Form-grinding Method proved very Efficient

the machine for locating the wheel laterally in the correct relation to the work. This comprises a block *L* (see Fig. 2) fulcrumed in bracket *M* which can be swung down out of the way when truing the grinding wheel. The work is then relocated by moving block *L* into place between the two set-screws *N* and *O*. As shown in Fig. 12, the diamond truing device consists of two rods *A* and *B*, which are held in the holder in an angular position so as to bring their two forward ends about 1½ inch apart. The plungers holding the diamonds are operated by micrometer screws so that each diamond point is adjustable independently.

Examples showing Advantages of Form Grinding. — The example of straight-in grinding shown in Fig. 13 is an excellent illustration of the advantage of this method as compared with traverse grinding. When this particular part was ground by the traverse method, the time for 100 pieces was seven hours, thirty minutes. By bringing the wheel straight in on the work,



A

Work: — Gas engine valve stem, 0.30 per cent carbon steel, not hardened.

Operation: — "Straight-in" grinding diameter of stem with a Norton (alundum) wheel, grain 38–46, grade J; 18 inches diameter, 6 inch face; speed, 1379 R.P.M. — 6500 feet surface speed; work speed, 255 R.P.M. — 25 feet surface speed; amount removed from diameter, 0.010 to 0.012 inch.

Remarks: — Wide-face wheel is fed straight in on work without any lateral traverse at the rate of 0.0005 inch per revolution of the work; 50 pieces turned out to each truing of wheel; production, 40 pieces in twenty-one minutes, twelve seconds; machine used, No. 12 Brown & Sharpe plain grinding machine.

B

Work: — Drive pinion made of cast iron.

Operation: — "Straight-in" grinding stem of pinion with a Norton (vitrified) crystolon wheel; grain 50, grade L; 18 inches diameter, 6½ inch face; speed, 1379 R.P.M. — 6500 feet surface speed; work speed, 79 R.P.M. — 75 feet surface speed; amount removed from diameter, 0.015 inch.

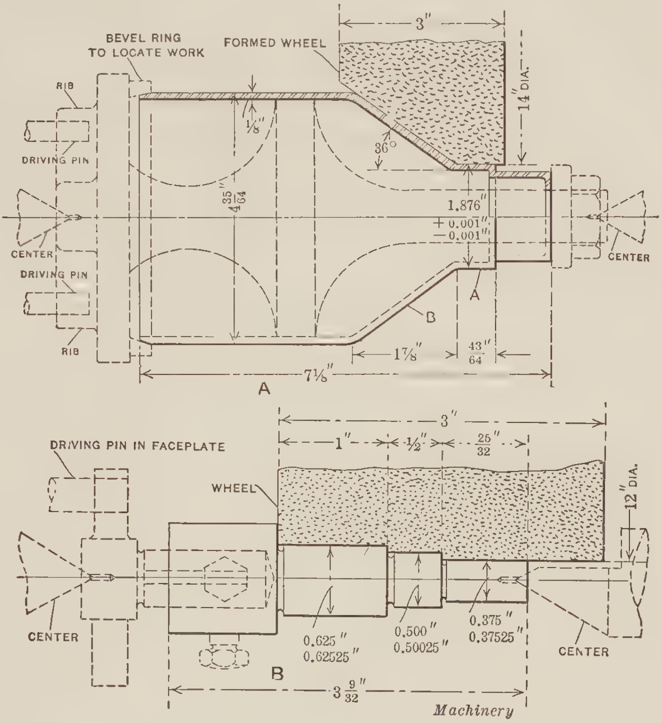
Remarks: — Wide-face wheel is fed straight in on work without any lateral traverse at the rate of 0.0005 inch per revolution of the work; 10 pieces turned out to each truing of wheel; production, 100 pieces in four and one-half hours; parts put through in lots of 100 pieces; machine used, No. 16 Brown & Sharpe plain grinding machine.

Fig. 14. Two Examples of Form Grinding — One illustrating Limitations and Other Advantages of this Method

the time was reduced on 100 pieces to two hours, eighteen minutes, without sacrificing accuracy or finish of work. The cast-iron pinion shown at *B* in Fig. 14 is another example which illustrates the advantage of straight-in grinding over traversing the wheel. On a lot of 100 pieces, the previous time by the traversing method was seven hours, forty-eight minutes. This time was reduced almost one-half by bringing the wheel straight in on the work, the grinding then being done in four hours, thirty minutes. The example *A* in Fig. 14 shows a little closer time between the traversing and straight-in methods of grinding. On forty pieces, the time required for traversing the wheel was twenty-six minutes, twenty-six seconds, and by bringing the wheel straight in on the work, the time for forty pieces was twenty-one minutes, twelve seconds — a gain of about five minutes. The reason that the straight-in method shows such a slight advantage in this case is because of the slenderness of the work and the care with which it has to be handled. The gain, however, is sufficient to warrant the use of the straight-in method of grinding in preference to traversing the work.

The example of straight-in grinding shown at *B* in Fig. 15 illustrates an important point in regard to operating the machine. On account of the shape of this particular part, it is necessary to use a special driver which is not readily put in place, and two methods were adopted for operating the machine. One method was to have a man mount the work and operate the machine; by this method the time for 100 pieces was fifty-three minutes. By having two men, one helper and one machine operator, the time on 100 pieces was reduced to forty-three minutes. For truing up the grinding wheel, a special truing device having three diamond holders was used, so that all three diameters on the wheel could be trued up at the same setting.

Grinding a Cylindrical and Conical Surface. — The cream separator bowl shell shown at *A* in Fig. 15 illustrates an example of work for which the form wheel method of grinding is particularly adapted. In this case, tapered and straight surfaces have to be finished, and the method of accomplishing this



A

Work: — Cream separator bowl shell, 0.18 to 0.25 per cent carbon hot-rolled strip steel, annealed, pickled and "limed," but not hardened.

Operation: — Grinding straight and tapered portions of bowl with a Norton (vitrified) alundum wheel, grain 24, grade M; 14 inches in diameter, 3 inch face; speed, 1364 R.P.M. — 5000 feet surface speed; work speed, 48 R.P.M. — 50 feet average surface speed; amount removed from diameter, 0.012 to 0.015 inch.

Remarks: — Wide-face wheel is fed straight in to grind bevel and straight portions in the following manner: first, wheel is fed straight in to rough (A) to within 0.003 inch of finished size; second, wheel is traversed sideways to finish (B); third, wheel is moved back 0.004 inch from bevel surface to finish (A); 25 to 200 pieces turned out to each truing of wheel; varies with grade of steel and annealing, the average being 50; production, 192 in nine hours.

B

Work: — Igniter shaft, 0.20 per cent carbon steel, not hardened.

Operation: — "Straight-in" grinding three external diameters with a Norton (alundum) wheel, grain 38–46, grade K; 12 inches diameter, 3 inch face; speed, 2069 R.P.M. — 6500 feet surface speed; work speed, 306 R.P.M. — 40 feet average surface speed; amount removed from diameter, 0.010 inch.

Remarks: — Wide-face wheel is fed straight in on work without lateral traverse; actual grinding time — one man mounting work, one man operating machine — 43 minutes for 100 shafts; work put through in lots of 100 pieces.

Fig. 15. (A) Form Grinding applied to a Conical Surface. (B) Grinding Three Diameters Simultaneously

is to first feed the wheel straight in to rough diameter *A* to within about 0.003 inch of the finished size. Then the work is moved sidewise so as to finish-bevel surface *B*. The work is again moved back from the wheel about 0.004 inch, whereupon the wheel is fed straight in to finish surface *A*, and, at the same time, take a light finishing cut from surface *B*. In this way, both surfaces are finished accurately.

Grinding Rifle Barrels. — The grinding of rifle barrels in large quantities has necessitated devising special equipment and means for handling the work expeditiously. It is no exception, therefore, to find that the wide face grinding wheel has been adapted with success to this work. Fig. 16 shows a Norton 10- by 36-inch plain grinding machine arranged for rifle barrel grinding. This particular rifle barrel, shown in Fig. 17, is over 26 inches long and is practically ground throughout its entire length. The barrel is ground taper from the muzzle up to within a short distance of the breech end and terminates in a 10-inch radius. The wheel used for this purpose is 5 inches wide, 20 inches in diameter, and is trued with a 10-inch radius for about one-half its face width, the remaining part of the face being trued straight. The swivel table of the machine is adjusted to the required taper.

This barrel is made from an unannealed forging of from 0.45 to 0.50 per cent carbon content. Usually it is ground after the bore of the barrel has been reamed, and, in some cases, slugs are inserted in the ends instead of having the centers fit directly in the bore. On this particular barrel, the external diameter is finished by the power and hand traverse methods. The taper portion of the barrel is ground by traversing the work past the wheel by power, whereas the curved surface is finished by hand. The operator, as soon as he finished the taper, brings the work slowly up against the radius on the wheel and finishes this portion of the barrel to shape and size.

On an average, thirty-five to forty barrels can be turned out between each truing of the wheel, but the straight portion of the wheel requires to be trued about twice for every truing of the curved section. The truing is done by taking a very light

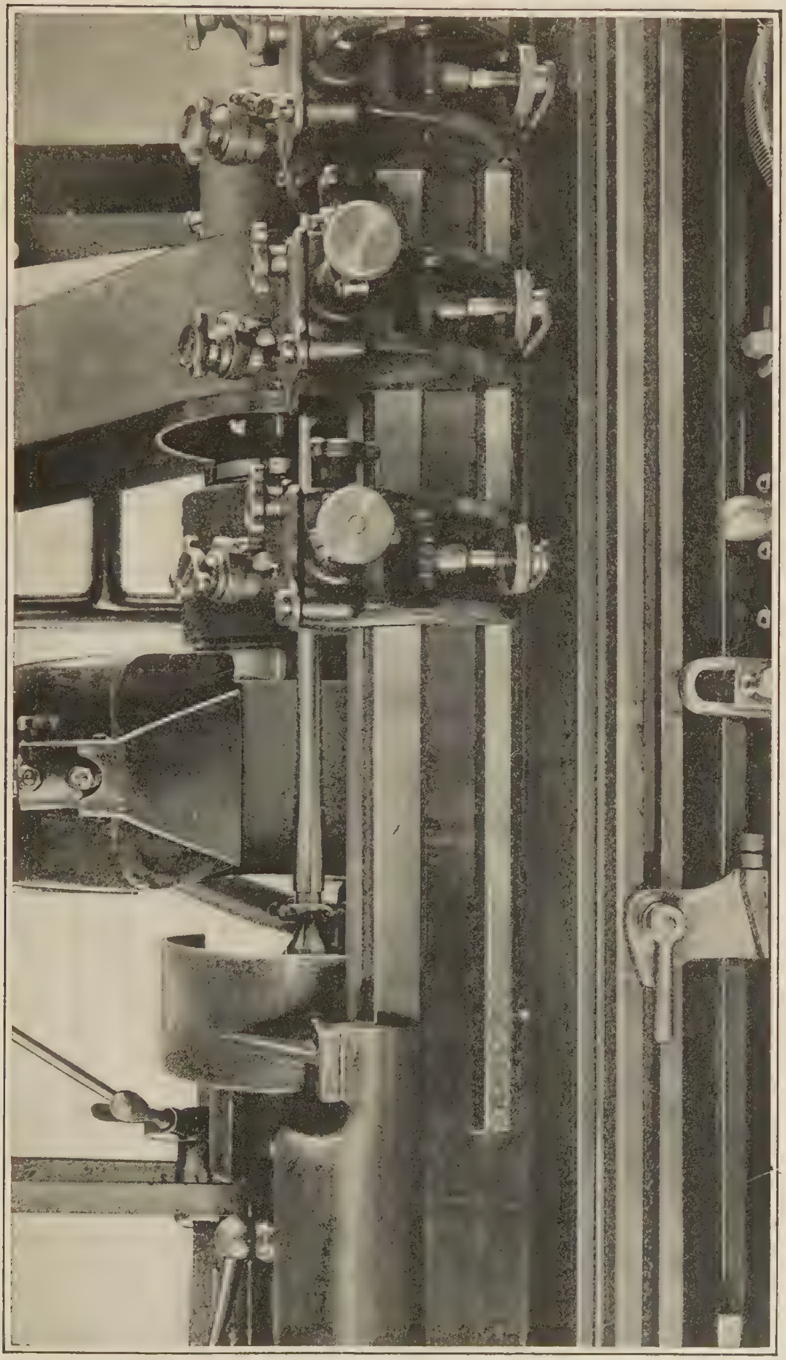
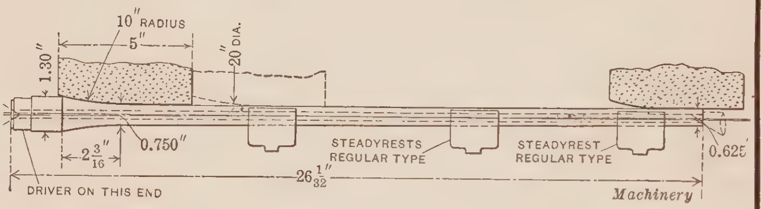


Fig. 16. Grinding Rifle Barrel on 10- by 36-inch Norton Plain Grinding Machine

cut with the diamond from the face of the wheel and does not change the size of the wheel perceptibly. The rate at which the work is traversed past the wheel varies to a considerable extent, but the usual practice is to take light cuts with coarse traverse feeds, practically the full width of the wheel being used per revolution of the work for roughing. Three standard Norton rigid steadyrests, located from 8 to 10 inches apart, are used for supporting the work. These steadyrests carry hardened and ground steel shoes which are finished to the same taper as that on the barrel.



Work: — Rifle barrel, 0.45 to 0.50 per cent carbon unannealed steel forgings.

Operation: — Grinding taper and radius with a Norton (vitrified) combination wheel, grain 38–36, grade K; 20 inches diameter, 5 inch face; speed, 1184 R.P.M. — 6200 feet surface speed; work speed, 150 R.P.M. — 35 feet average surface speed; amount removed from diameter, 0.015 to 0.020 inch.

Remarks: — Power traverse is used for grinding taper, and upon completion of this section, work is fed slowly by hand against wheel to finish radius; 35 to 40 barrels to each truing of wheel; three rigid steadyrests used 8 to 10 inches apart; production, 20 completed rifle barrels per hour; machine used, 10 by 36 inch Norton plain grinding machine.

Fig. 17. One-operation Method of Grinding Rifle Barrel

Another interesting example of rifle barrel grinding is shown in Fig. 18. As will be seen by referring to these diagrams, this rifle barrel is handled in an entirely different manner from the one previously referred to. Instead of traversing the wheel along the work straight from the radius section to the muzzle, the wheel is fed in at intervals along the diameter of the work, the reason for this being that the taper on the barrel is not continuous but changes at five points. To complete the barrel requires five operations and five Norton 10- by 36-inch plain grinding machines which are fitted up with special attachments for this work.

For performing operation *A*, the machine is provided with a headstock locating attachment which fits over a locating block on the left-hand end of the table, so that the headstock can be brought up until the center engages with the center hole in the locating attachment. The locating block for the headstock is common to all of the five machines used for this work. This device is provided for relocating the headstock after the center has been ground, which is necessary because of the wear that takes place. Operation *A* consists in spotting the barrel in the center, and the locating block on the swivel table is placed properly for locating the steadyrest to support the work at this point. The table is located by a pin at the front of the base which engages with a slot in a block attached to the sliding table. In this way the rifle barrel is always in the correct position relative to the grinding wheel for spotting the center of the barrel.

The second locating block on the sliding table (shown to the right of the one just mentioned) is used for locating the table when the wheel truing device is being used. For operation *A*, the swivel table is set in the correct position for grinding straight work, and the former on the truing device is provided with the necessary double taper so as to produce the correct shape on the face of the 3-inch wheel. After the first barrel has been ground, the micrometer stops on the steadyrests and the positive stops on the cross-feed mechanism are properly set to obtain the correct diameter on the barrel. These stops are left in this position until it is necessary to adjust them as the wheel wears down. The shoes used in the steadyrests are made from hardened steel and are ground to fit the shape of the barrel at the points where they contact with it.

Operation *B* consists in spotting the barrel by the use of a 4-inch face wheel close to the breech end. For supporting the barrel for this operation, a cap-type steadyrest is placed on the table in the correct position by means of a locating block, and the shoe of this rest engages that portion of the barrel that has already been ground. A regular type solid steadyrest is placed on the table directly in front of the grinding wheel to give additional support to the work. A locating pin engaging with the

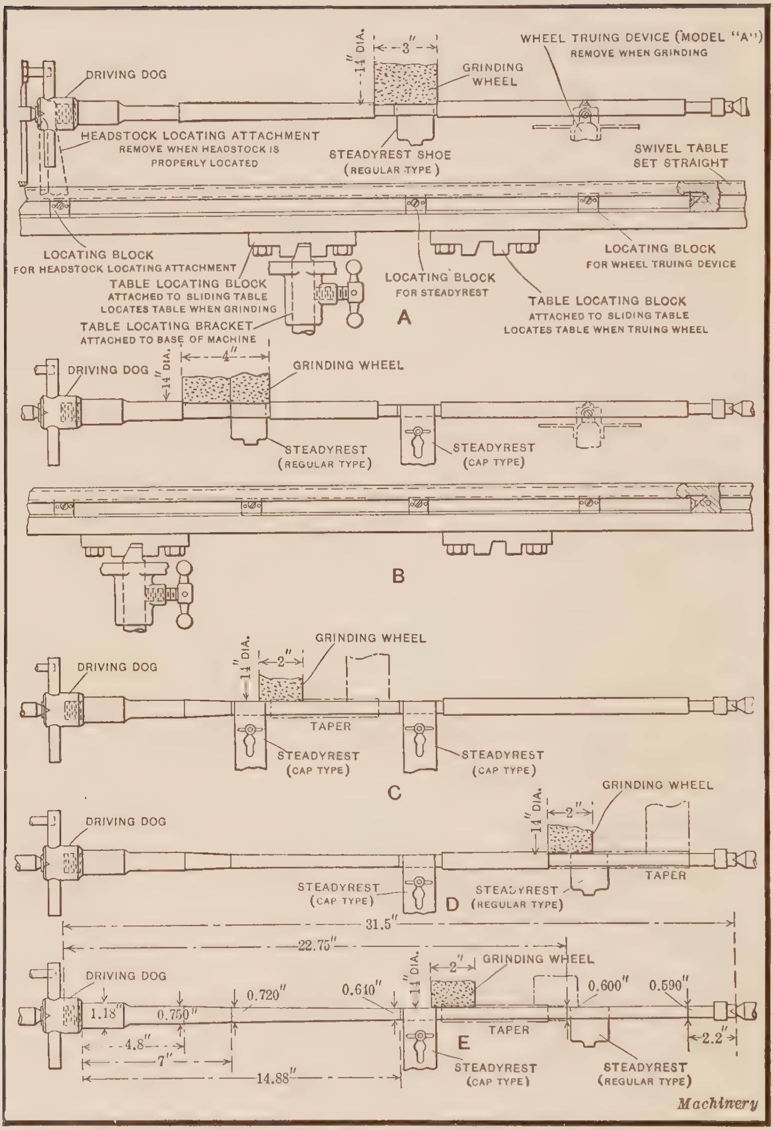

DRIVING DOG
14" DIA.
3"
GRINDING WHEEL
WHEEL TRUING DEVICE (MODEL "A")
REMOVE WHEN GRINDING
HEADSTOCK LOCATING ATTACHMENT
REMOVE WHEN HEADSTOCK IS PROPERLY LOCATED
STEADYREST SHOE (REGULAR TYPE)
SWIVEL TABLE SET STRAIGHT
LOCATING BLOCK FOR HEADSTOCK LOCATING ATTACHMENT
TABLE LOCATING BLOCK ATTACHED TO SLIDING TABLE LOCATES TABLE WHEN GRINDING
TABLE LOCATING BRACKET ATTACHED TO BASE OF MACHINE
LOCATING BLOCK FOR STEADYREST
LOCATING BLOCK FOR WHEEL TRUING DEVICE
TABLE LOCATING BLOCK ATTACHED TO SLIDING TABLE LOCATES TABLE WHEN TRUING WHEEL
A
DRIVING DOG
14" DIA.
4"
GRINDING WHEEL
STEADYREST (REGULAR TYPE)
STEADYREST (CAP TYPE)
B
GRINDING WHEEL
DRIVING DOG
14" DIA.
2"
TAPER
STEADYREST (CAP TYPE)
STEADYREST (CAP TYPE)
C
GRINDING WHEEL
DRIVING DOG
14" DIA.
2"
TAPER
STEADYREST (CAP TYPE)
D
STEADYREST (REGULAR TYPE)
31.5"
22.75"
DRIVING DOG
14" DIA.
2"
GRINDING WHEEL
1.18"
0.750"
0.720"
0.640"
0.600"
0.590"
4.8"
7"
14.88"
TAPER
E
2.2"
STEADYREST (CAP TYPE)
STEADYREST (REGULAR TYPE)
Machinery

Fig. 18. Example illustrating Five-operation Method of Grinding Rifle Barrels

table locating block is attached to the sliding table and correctly locates the work with reference to the grinding wheel for this operation, as was the case in operation *A*. The wheel truing device, in this case, also has two tapers so as to produce the correct shape on the face of the grinding wheel. When performing this operation, the swivel table is set, as before, for grinding straight work, the wheel being trued to the correct taper.

Operation *C* consists in traversing the work past a 2-inch face wheel. For this operation, the table is adjusted to the required taper and two cap-type steadyrests are located, as indicated, for supporting the work. In this operation, the two tapers produced by the form wheels in operations *A* and *B* are matched up. The wheel is trued by using the table traverse, the diamond being held in a holder attached to the footstock of the machine.

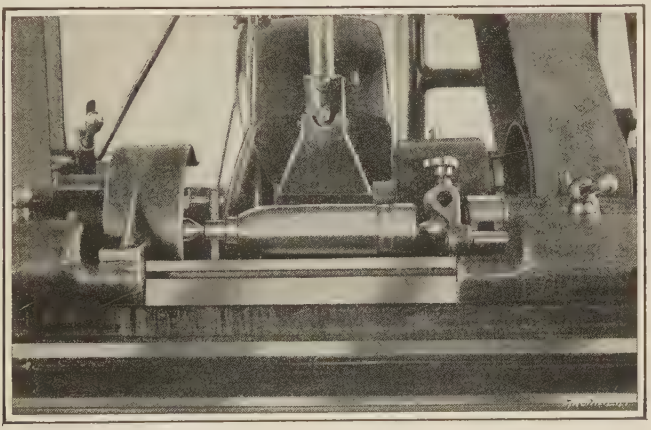


Fig. 19. Grinding Shrapnel Shell on Norton Special-purpose Grinding Machine

Operation *D* is also a traverse grinding operation and the headstock is located in the same manner as for operation *A*. A cap-type steadyrest is used at the center of the barrel and is located by the block on the swivel table. A regular type steadyrest is placed to the right of the cap-type steadyrest and is also located in the correct position by means of a locating block. The swivel table is adjusted to the correct taper and a 2-inch face grinding wheel is used. The power traverse is used for this traverse grinding operation. The grinding wheel is trued by means of a diamond carried in the holder on the footstock of the machine.

Operation *E* is performed in a somewhat similar manner to operation *D* and is the final operation on the barrel. The production from each machine is figured on a basis of thirty-five rifle barrels per hour, giving a total of about 350 completed rifle barrels in ten hours from five machines. For grinding this barrel, it will be noted that full advantage is taken of the wide face wheel, trued to different tapers, and bringing it straight in on the work. This, combined with traversing the work, enables the greatest production to be obtained on this peculiar shape of rifle barrel.

Form Grinding Shrapnel Shells. — Many shrapnel shells are finished by grinding. The interior surface of the shell is rough-turned to within from 0.030 to 0.080 inch of the finished size and is then finished to the required limits and shape by grinding, as shown in Fig. 19. It is claimed that the finishing operations are more speedily performed in this manner and that a more accurate and concentric shell is produced.

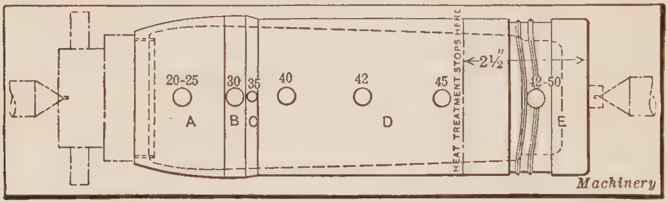


Fig. 20. Diagram showing Scleroscope Hardness Test of Heat-treated Shrapnel Shell at Various Points along its Surface

The varied heat-treatment given to the shell on the closed end and "nose" leaves it harder in some sections than others, as indicated in Fig. 20. The section *E*, 2½ inches from the closed end of the shell, must strike from 42 to 50 on the scleroscope, and the section *A* at the nose must strike between 20 and 25. The section marked *D*, or that part of it to the left of the line that marks the limit of the heat-treating on the closed end, has not been heat-treated at all, and, partly on this account and also because of the gradually diminishing thickness of the shell along this section, it strikes between 40 and 45, decreasing as the thickness of the wall diminishes, until at *C*, the section strikes but 35. Section *B*, adjacent to the annealed nose of the shell, strikes about 30 on the scleroscope.

Some manufacturers do not subject the shell to this heat-treating and tempering process and omit the annealing and machining of the nose after the nosing in operation. This leaves the nose with considerable stock to remove and in such a condition, as regards hardness, that the grinding machine becomes a necessity. On account of these varying degrees of hardness of the shrapnel shell, it will be seen that it is difficult to secure wheels of the right grain and grade to suit all of these conditions. The Norton Grinding Co. has developed methods of grinding shrapnel shells and the following illustrations and description apply to the work as done on Norton grinding machines.

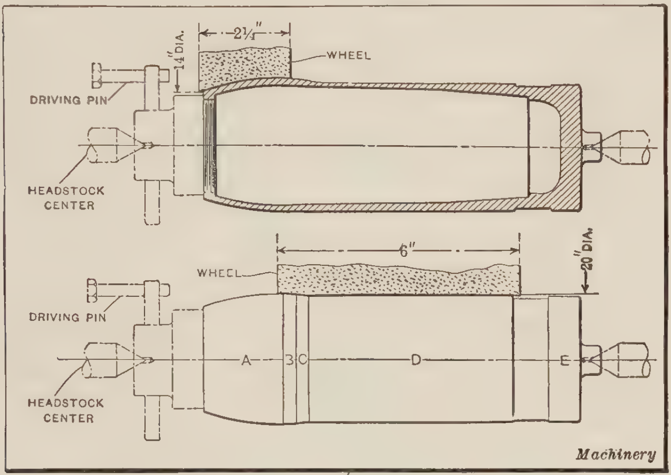


Fig. 21. Two-operation Method of Grinding Shrapnel Shells

Fig. 21 shows the two-operation method of grinding a shrapnel shell. Section *A*, at the open end of the shell, is covered by a wide-faced wheel formed to shape that finishes the radius on the nose at one in-feeding of the wheel. Sections *B*, *C*, and *D* are covered by a wide-faced wheel formed to shape so as to finish these three surfaces at one in-feeding of the wheel. Section *E*, at the closed end of the shell, is finished completely by turning.

Some manufacturers use a three-operation method of grinding the shrapnel shell, as illustrated in Fig. 22. In this case, the sections *A* and *D* are first ground with the same wheel, as American manufacturers deem it advisable to grind surface *A* rather than to finish it by turning. The second stage in this grinding is the finishing of the nose *E* with a formed wheel, and the third stage is the finish-grinding of the body at points *B* and *C*.

The procedure followed in grinding shrapnel shells by the two-operation method is first to screw plugs into the open end of the shells, as shown in Fig. 21. The outer ends of these plugs are centered, and the projection, left on the closed end of the shell with the center intact, acts as a means of supporting the shell. Some Canadian manufacturers vary this practice by cutting off the center projection on the closed end of the shell and fitting a cap with a center hole over the closed end. Others use a ball-bearing cup center to carry the closed end. American manufacturers, however, leave the center projection on the shell until after the grinding has been finished.

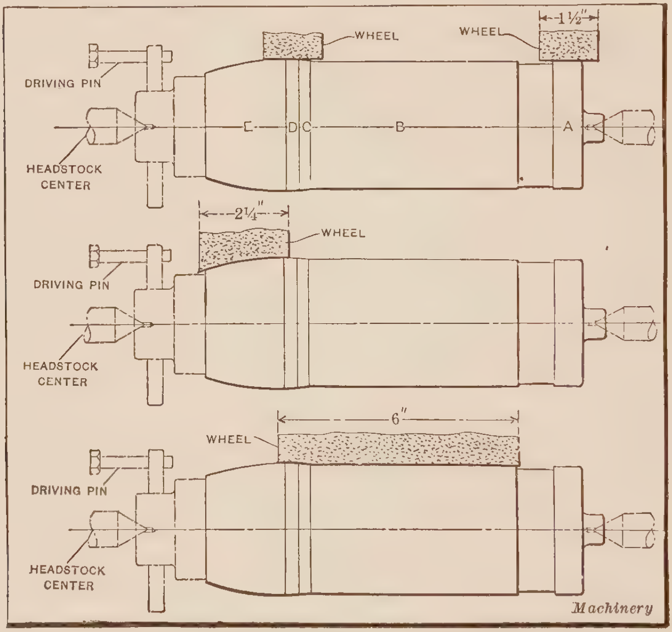


Fig. 22. Three-operation Method of Grinding Shrapnel Shells

In grinding the nose end of the shell, the amount of metal removed varies from 0.020 to 0.090 inch on the diameter. The grinding wheel operates at from 6000 to 6250 surface feet per minute. The speed of the work is 75 revolutions per minute, or a surface speed of practically 75 feet, and the machine used is a Norton 6- by 32-inch plain grinder. The wheel used is generally 14 inches diameter by $2\frac{1}{4}$ inches face. The wheel requires truing for every five to twenty shells, depending upon the amount of metal removed and the hardness of the shell. For truing, a simple radius fixture carrying a diamond is used. This wheel truing device is applied in the same manner as the steadyrests used for supporting the work. The diamond is mounted in a swinging arm that is operated by a hand lever. By successive cuts across the wheel, the desired shape is attained.

For grinding the body, either a 10- by 24-inch special-purpose machine or a 10- by 36-inch grinding machine is employed. The amount of metal removed from the body varies from 0.030 to 0.075 inch on the diameter, and the limits vary from 0.002 to 0.010 inch, depending largely on the requirements of the plant in which the work is being done. The wheel used on the body is 20 inches in diameter, 6 inches wide, and is shaped somewhat like an ordinary straight cup-wheel, except that the annular wall of the wheel is thicker to allow for wear and wheel truing, inasmuch as the grinding is done on the periphery. The wheel is trued to conform to a required shape by means of a special truing device. This is so arranged that the diamond, while being traversed across the wheel-face, is made to follow the contour of a former, the shape of which is thus reproduced on the grinding wheel.

For grinding the body, the wheel must be trued after from ten to twenty-five shells have been ground, depending upon the amount of metal removed and the hardness of the shell. In grinding shrapnel shells, the usual method is to fit a lot of the shells with the driving plugs and carry them all through to completion before removing the plugs.

Form Grinding Splined Shafts. — Splined shafts for automobile transmissions illustrate another application of the form wheel to straight and circular surfaces. For this class of work, the No. 20 Bath multiple-key shaft grinding machine shown in

Fig. 23 is adapted. This machine carries a form wheel which simultaneously works on both sides of the spline and also on the radius between the splines. The wheel is kept trued to the proper shape by means of the special wheel-truing device shown to the right of the illustration; this is described in Chapter VIII (see Figs. 23 and 24).

The work is held on centers and is driven by a dog in the usual manner. The head carrying the headstock center is rotated to index the work for grinding the various splines and several different methods are used for accomplishing this work. On the main drive shaft, shown at *A* in Fig. 24, the method of grinding is to first rough-grind all around the shaft to within 0.002 inch of the finished size, then true up the wheel with a special wheel-truing device, and take a finishing cut all around, four to five traverses per each spline being made for roughing and two traverses for finishing.

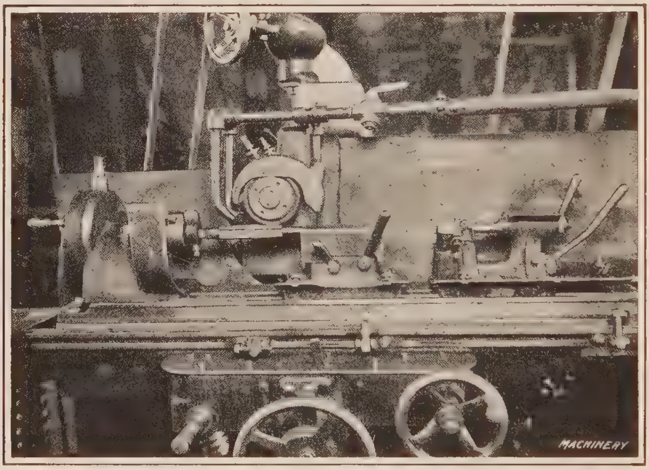
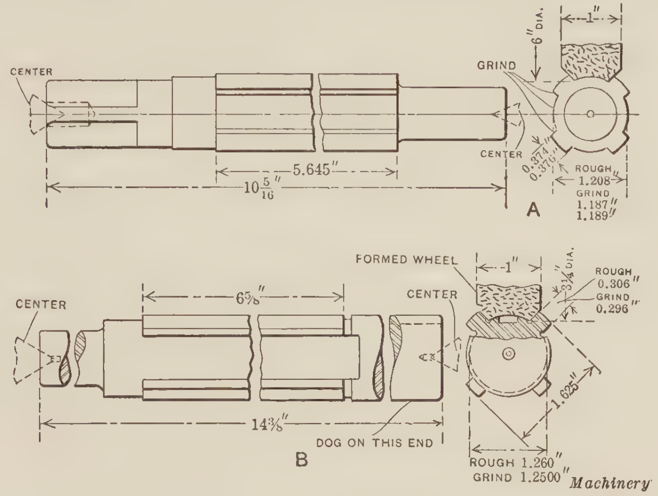


Fig. 23. Bath Multiple-key Shaft Grinding Machine arranged for Grinding a Splined Transmission Shaft

In the example shown at *B*, which is practically the same type of shaft, the method of handling is the same but a different wheel is used. For example *A*, a Detroit combination wheel, grain 10-14, grade F, is used. This wheel is a combination of two different size grains and two different bonds; the sides



A

Work: — Main transmission drive shaft, 0.20 per cent carbon, open-hearth steel, carbonized and hardened.

Operation: — Form grinding splines and radius with a Detroit (vitrified) combination wheel, grain 10–14, grade F; 6 inches diameter, 1 inch face; speed, 3185 R.P.M. — 5000 feet surface speed; traverse work speed, 4.3 linear feet per minute; amount removed, 0.010 inch from each side of splines; 0.020 inch from diameter.

Remarks: — Sides of splines and radius are first rough-ground all around to within 0.002 inch of finished size, then wheel is trued with a special wheel-truing device and shaft is finish-ground all around; number of traverses, four to five for each spline for roughing, two traverses for finishing. A combination wheel with hard bonded fine grain sides, and soft bonded coarse grain center is used; production, 60 pieces in ten hours; machine used, No. 20 Bath multiple-key shaft grinding machine.

B

Work: — Main transmission drive shaft, 0.50 per cent carbon steel drop-forging, hardened.

Operation: — Form grinding splines and radius with a Norton (vitrified) alundum wheel, grain 46, grade M; 3¼ inches diameter, 1 inch face; 2500 R.P.M. — 2125 feet surface speed; traverse work speed, 8¼ linear feet per minute; amount removed 0.007 to 0.010 inch from each side of the splines; 0.014 to 0.020 inch from diameter.

Remarks: — Sides of splines and radius are first rough-ground by indexing the work after each traverse of the wheel, and two or three complete indexings made for roughing and finishing; wheel trued with special truing device; 12 to 15 pieces turned out per truing of wheel; production, 100 pieces in nine hours; 300 pieces ground by one wheel; machine used, No. 20 Bath multiple-key shaft grinding machine.

Fig. 24. Splined Transmission Shafts produced by Form Grinding

of the wheel which operate on the splines are of fine grain, hard bond, whereas the center is of coarse grain and soft bond. For the example shown at *B*, the wheel used is a Norton alundum, grain 46, grade M, of practically a uniform grain throughout, and is not of harder bond on the sides than in the center. With the wheel used in example *A*, it is necessary to true it up before taking the finishing cuts on every piece, whereas the wheel used in example *B* turns out from twelve to fifteen pieces to each truing of the wheel. The production in example *A* is sixty pieces in ten hours, whereas the production at *B* is 100 pieces in nine hours. From a study of these two examples of work, it would appear that a hard side, soft center wheel is not as satisfactory, from a production standpoint, as a wheel of an even bond and grain throughout.

Form Grinding Crowned Pulleys. — One of the very simple and effective discoveries in the application of belting to the transmission of power has been the crowning of the face of the pulley, *i.e.*, making the center larger in diameter than the edges, for the purpose of guiding the belt in a straight line and thereby keeping it in position without using such mechanical means as belt guides or flanges for this purpose.

Some authorities recommend that the height of the crown should be $\frac{1}{20}$ of the width of the face of the pulley, some $\frac{1}{24}$, some from $\frac{1}{8}$ to $\frac{1}{4}$ inch in height per foot of width. The crowning or increasing of the diameter of the pulley at the center makes it possible to dispense with flanges or mechanical means for guiding the belt, due to the tendency on the part of the belt to always climb to the high point on the pulley. Consequently, the crown has but one object, and that is to guide the belt. The ideal condition for the transmission of power, insuring the greatest efficiency of the belt, is when the face of the pulley is absolutely straight and true. Therefore, the nearer we can approach this condition, the more efficient will be the belt.

There are two principal factors which determine the position that a belt takes upon a crowned pulley, and these are modified by each other. First: The exact location of the highest point of the crown on the face of the pulley. Second: The diameter of the two extreme edges of the pulley. To insure the belt driving in its proper place on the pulley, the highest point of the crown should be exactly in the center and the two edges of the pulley of exactly the same diameter.

The common method of crowning pulleys in general use is by two tapers, as illustrated in the left-hand view of Fig. 25.

This method is selected principally because of its easy application in manufacturing (excluding the grinding process as a means of producing crowns) but has always been looked upon as being inefficient. The curved-face crown, when the curve can be held uniform throughout, is a better means of crowning and more effective. The illustration of the position of the belt in Fig. 25 has been exaggerated to show the effect of crowning the pulley by the two-taper process. It will be noticed that the greatest tension on the belt is at point *C*, and naturally a strain is imposed at this point. The really effective driving is done somewhere between the center and outside edges and may be represented by the space between *A* and *B*. Because of the stiffness of the belt (which is increased as the speed increases), the belt has a tendency to assume the position shown by the illustration. In actual practice, the pressure between the two extreme edges varies at different points, being the least near the edges and the greatest at the center. The real effective driving portion of the belt is between the points *A* and *B*.

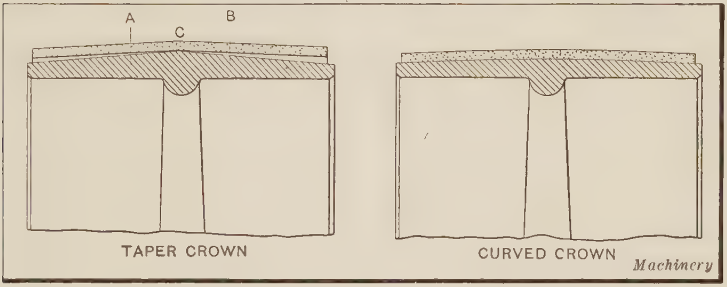


Fig. 25. Belt Contact on Pulley having a Double-taper Crown — Belt Contact when Crown is formed by a Uniform Curve

On the right of the same illustration is shown a pulley crowned by the form grinding process, employing a straight-in cut. It will be seen that this crown has a symmetrical curve throughout the entire face of the pulley. By this practice, it is possible to produce pulleys with a crown of the minimum height, and, because of the accuracy of the crown, it will still guide the belt. The two extreme diameters on the edges of the pulley are held to a given dimension within a limit of 0.001 inch, the curve being symmetrical from edge to edge, which insures the highest point of the crown coming at the center and gradually decreasing toward the edges with no abrupt differences in diameter from point to point. The fact that the belt lies uniformly over the face of the crown and approaches the ideal condition of a flat surface on the pulley insures driving qualities and a power transmitting ability in the belt which are materially greater than when a crown is employed using the two-taper method.

Extensive investigations on the shape and height of the crown for pulleys indicate that, for ordinary conditions employed in the operation of machine tools, and with the ordinary materials generally used for such purposes, the speeds, belts (whether leather or cotton), etc., have little bearing on the required height of crown to insure a satisfactory guiding of the belt, if such a crown is produced by grinding. The width of the face of the pulley is really the only important factor. This follows because of the possibility of producing the pulley face with a curve which is symmetrical throughout from edge to edge and with diameters at the extreme edges of the pulley so nearly alike that the effect of their difference is negligible. A formula used by the Norton Grinding Co. which, in actual practice, is producing satisfactory work is: $\frac{1}{200}$ of pulley face $+ 0.020$ inch $=$ height of crown.

By the wide-face grinding process, it is also possible to produce, in addition to the crowning of the face, other shapes in connection with the pulley diameter. For instance, special cone pulleys having angular faces joining one cone step to the adjacent one may be formed at the same time that the crown is put on the various steps of the cone. This method is convenient in crowning the faces of tight and loose pulleys where the loose pulley is of a lesser diameter than the tight. A special fixture is necessary in doing such work. The fixture for truing the wheel to grind crowns is described in Chapter VIII. (See Fig. 20.)

It must be remembered, in crowning pulley faces in this manner, that the wheel is fed straight in and does not travel laterally, so that the form of the wheel-face is what actually produces the crown on the pulley. This is another phase of the application of the wide-face wheel and straight-in cuts for form grinding.

CHAPTER III

INTERNAL GRINDING

INTERNAL grinding, or the grinding of holes, is not only a broad subject but is one of great importance to the machine tool builder as well as the general manufacturer. Formerly, internal grinding was done only where hardened parts were used and the holes had to be finished to an exact size. In many cases, lapping was resorted to for finishing holes in the hardened pieces, only 0.001 or 0.002 inch being left for this purpose, in order that the operation should not take more time than absolutely necessary. The internal grinding machine has completely displaced lapping from the rough, and, now, lapping as a finishing operation is used only when surfaces of great smoothness or extreme accuracy are required. With the improvements made in internal grinding machines, the field has been developed and extended to such a degree that not only is it considered good practice to grind hardened work but also parts made of soft steel, cast iron, and bronze, whenever accuracy is necessary.

Internal grinding is done both on universal grinding machines and on special types of machines designed exclusively for handling this work. The use of the universal grinding machine on this work is confined more particularly to tool-rooms for making jig bushings, and similar parts, and is not commonly employed in a manufacturing way for producing interchangeable work in large quantities. The reason is that the universal grinding machine being designed for handling plain grinding, face grinding, and internal grinding, cannot be so constructed as to be as efficient on any one line of work as a machine which is designed and built for that special purpose.

Universal grinding machines are regularly furnished with internal grinding attachments consisting of a bracket supporting the grinding wheel and spindle which can be mounted on the swivel base carrying the main grinding spindle. Fig. 1 shows the internal grinding attachment furnished on a Brown & Sharpe universal grinding machine. This attachment is supported on the slide carrying the wheel-spindle, the slide being turned 180 degrees from the position it usually occupies when the machine is arranged for plain grinding. To use the internal grinding head, the wheel-spindle used in plain grinding is removed and a special arbor with pulley for driving the internal attachment is substituted. The vertical driving belt is crossed and the grinding spindle rotates as shown by the arrow.

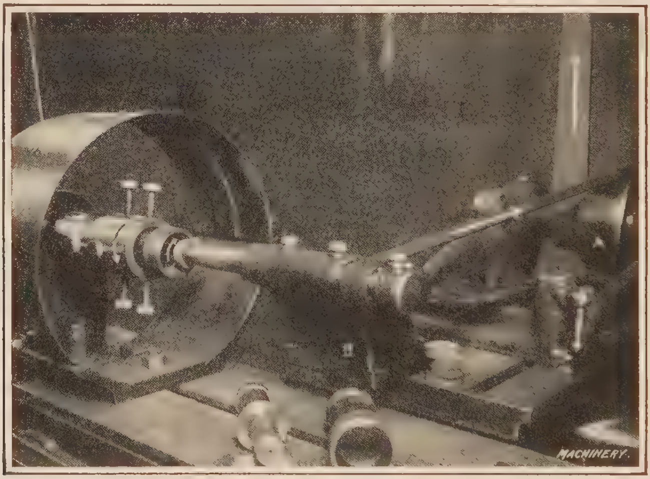


Fig. 1. Internal Grinding Attachment applied to Brown & Sharpe Universal Grinding Machine

In operation, the grinding wheel may be brought in contact with either the front side or the rear side of the hole in the work. The relation of the wheel to the work differs, however, in general practice, among the makers of the different types of machines; this point will be treated more fully later.

Internal Grinding Machines. — There are two general types of internal grinding machines in use. In one type, the work head is stationary and the wheel-spindle is traversed to and from the work. The wheel-spindle moves forward and back during the grinding and is moved away from the work for the purpose of gaging. In the other type, the wheel-spindle is supported by a stationary portion of the frame, and the work head is mounted on the table of the machine and travels to and from the grinding wheel. The former type is used to a large extent in machines especially designed for internal grinding, while the second type follows the construction of the universal grinding machine more closely

Internal grinding machines, of course, are made in different sizes adapted for grinding a large range of work and also in small sizes with special features, in some cases, for grinding small holes exclusively. They may be subdivided, also, into two classes: One adapted for internal grinding exclusively and another type in which a combination machine is furnished which will grind both internal and external diameters on the work at the same chucking. In the following, one machine of each type will be illustrated and described.

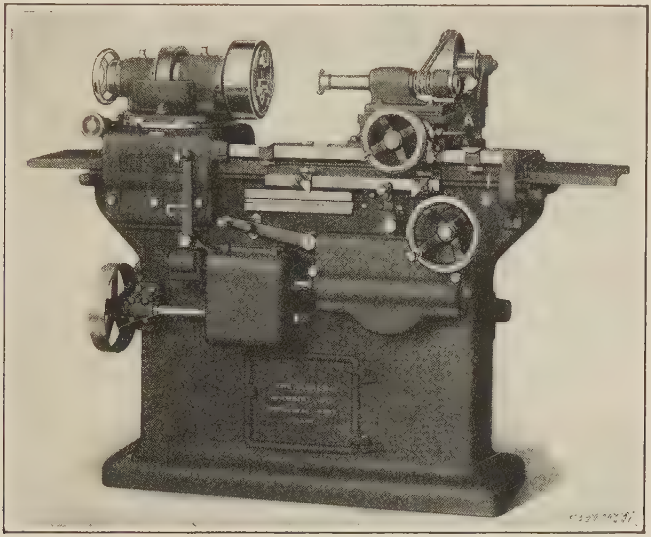


Fig. 2. Heald Internal Grinding Machine

Heald Internal Grinding Machine. — A machine designed especially for internal grinding, which is built by the Heald Machine Co., is shown in Fig. 2. In this machine, the designer has departed from previous types, which were built on the plan of the universal grinding machine, and put the headstock on a bridge at the left-hand end of the machine, giving it a firm and solid support. The grinding wheel-spindle is mounted on a cross-slide *A* carried on the main table *B* of the machine, which gives a solid support to the wheel-spindle. The wheel-spindle is driven from the overhead countershaft by a belt connecting with an idler pulley at the rear of the cross-slide, and the speed for the grinding spindle is controlled by the diameter of the pulley on this spindle.

The speed at which the work rotates is varied by change-speed mechanism forming a part of the countershaft. The changes of table feeds, *i.e.*, the speed at which the wheel travels through the work, are effected by operating the lever *C*. The headstock will swing to an angle up to 45 degrees either side of the center-line, for grinding tapered holes, and it is graduated both in degrees and in inches of taper per foot. This type is especially adapted for producing interchangeable parts in large quantities, because of the firmness and rigidity of the work support and the wheel support, enabling relatively soft and free cutting wheels to be used. The machines are made in two styles, one being fitted with both power and hand feed, and the other with a pilot handwheel for hand feed only.

Rivett Internal Grinding Machine. — For small work, such as grinding bushings, sleeves, and similar parts where high peripheral wheel speeds are necessary, the internal grinder shown in Fig. 3, built by the Rivett Lathe & Grinder Co., is especially suited. In this machine, the wheel-spindle *A* is held in a bracket *B* fastened to a slide that can be traversed at right angles to the travel of the work-table by operating handwheel *C*. Button *D* is used to engage the cross-feed for the wheel slide. The wheel-spindle is driven by two belts from the rear countershaft, which, in turn, is belted to the overhead works from which suitable speeds can be obtained by means of the cone-pulley countershaft.

The table of the machine is in two sections; the lower section is mounted on the base and slides on cross-bearings, being controlled in its movement by a reciprocating mechanism so designed that as the center of the stroke is approached the speed of the table is slightly retarded. This speed variation does away with the tendency of the wheel to take a lighter cut at the center of the work, and, at the same time, allows a coarser feed. Three different feeds for the table, independent of the head, are obtained through a three-step cone pulley at the rear of the machine. The table may be hand-operated by pilot wheel *F*; when operated by power, reciprocation of the table can be stopped by loosening clamp *G* without stopping the machine. The upper section of the table is arranged to swivel 5 degrees in either direction from the center and is adjusted by hand screws *H*.

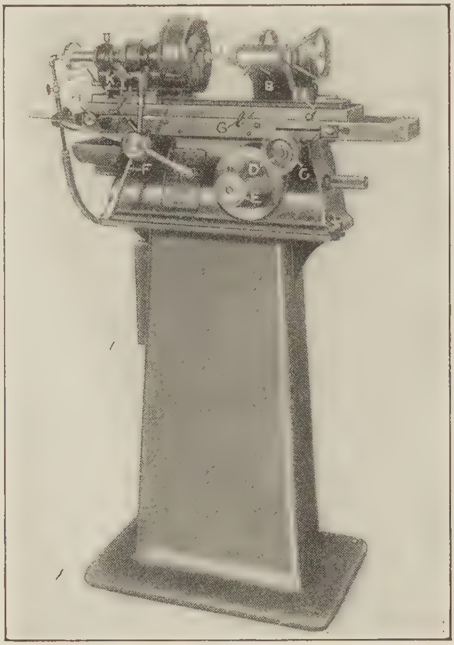


Fig. 3. Rivett Internal Grinding Machine

The base, upon which the work head rests, is graduated in degrees and the slide can be set at any angle up to 90 degrees in either direction. The work head is mounted on a cast-iron plate fitting the table slide and can be moved any required distance along the slide and clamped in position by lever *L*. The front end of the work-spindle is ground on the inside to hold split chucks and the rear end to fit a draw-in spindle furnished with the machine. Special fixtures are provided, so that it can be adapted to a general line of tool-room work for external grinding, etc.

Bryant Chucking Grinder. — Another type of grinding machine that is used for internal work as well as for external work is shown in Fig. 4. This is built by the Bryant Chucking Grinder Co. The machine is compact, it is possible to swing the wheel-spindle out of the way to gage the work, and, on the multiple-spindle type, external and internal diameters can be ground at the same setting, thus insuring that they are concentric with each other.

The work is held in a chuck *A* operated by handwheel *B*. This chuck is driven by pulley *P* and the work head has an angular adjustment for grinding tapers up to and including 30 degrees. Internal grinding is done with wheel-spindle *C*, whereas spindle *D* is used for external or face grinding. Spindle *D* is driven from the overhead works by a belt running on pulley *E*, and spindle *C* is driven from the same pulley by a separate and shorter belt. The wheel slide *F* is held on a hardened and ground cylindrical bar and can be swung on this bar to obtain the cross-feed for diameter control and face grinding. The diameter control is secured through hand-wheel *G* which carries an automatic knock-off cam operating through lever *H*. The backward and forward motion for the wheel slide is secured through a belt running on pulleys *I*; the gear *J* carries

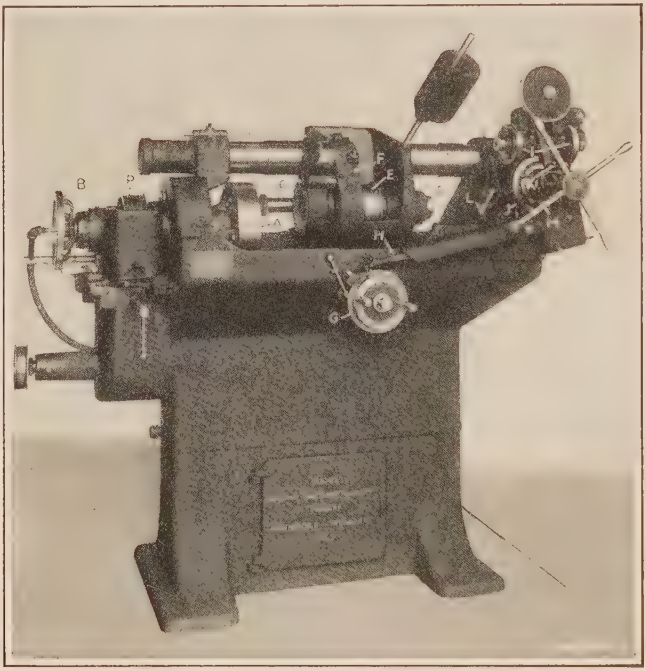


Fig. 4. Bryant Two-spindle Chucking, Face, and Hole Grinder

reversing trips for controlling the length of traverse. An automatic trip is also provided for throwing out the feed of the work slide. The reversal of the wheel slide can be effected by hand lever *K*, whereas lever *L* is used to disengage the power traverse. The pilot wheel *M* is for moving the slide back and forth by hand.

Internal Grinding-wheel Spindles. — In the grinding of small holes having a length of, say, four or five times their diameter, some difficulty is often experienced in getting wheel-spindles which are stiff enough to grind absolutely straight holes, owing to the tendency of the wheel-spindle to spring away from the work when its length is many times its diameter.

On spindles for grinding holes 2 inches in diameter and larger, it is the universal practice to keep the bearings close to the grinding wheel, the bearing as well as the wheel passing into the hole in the work. The smaller the hole to be ground, of course, the higher the spindle speed should be, to give the wheel a reasonable surface velocity. About 6000 feet per minute has been demonstrated to be a desirable surface speed for plain grinding machines and relatively large wheels, but it would require excessively high speeds for internal spindles to secure this circumferential velocity in running small wheels for grinding small holes, and these speeds would involve lubrication difficulties and extreme refinement in the adjustment of bearings, which it is not so easy to secure in internal spindles of small diameter. The modern grinding wheel, which can be furnished in soft and free cutting grades, now renders it unnecessary for internal grinding spindles to run at such extremely high speeds to produce high-grade work in large quantities, and this has simplified, to a great degree, the problem of getting suitable spindle speeds for internal grinding machines.

Brown & Sharpe Internal Grinding Spindle. — The internal grinding spindle shown in Fig. 5 is used on universal grinding machines. It consists, primarily, of a spindle of comparatively small size mounted in a bearing in telescopic tubes of sufficiently large diameter to give the required rigidity. These tubes or shells are longitudinally adjustable relative to each other and support the bearings for the spindle in close proximity to the grinding wheel. The small diameter of the spindle enables it to be revolved at the high speed necessary. The pulley spindle *A* is mounted in two annular ball bearings which take the pull of the belt. The bronze box *B* for the wheel-spindle is tapered on the outside to fit in the tapered hole of the outer shell, and this shell is made to screw onto the inner shell. The outer shell moves the bronze box longitudinally toward or from the inner shell, thus decreasing the end play of the wheel-spindle collar *C*. When the outer shell has been screwed onto the inner one far enough to take up all end play of collar *C*, still further movement will force the box into the taper end of the outer shell and close it to compensate for wear. After the box has been forced far enough into the tapered hole, the outer shell is unscrewed sufficiently to relieve the pressure on the collar and make a running fit. In this spindle, provision is made for excluding dust from the bearings, and rigidity at high speeds is attained.

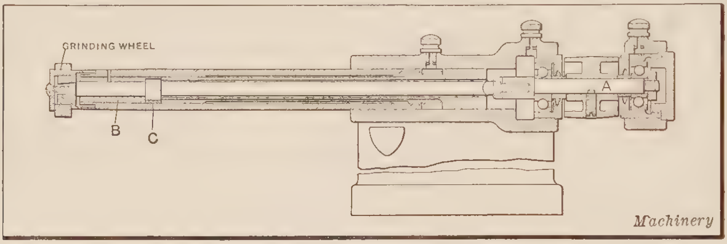


Fig. 5. Brown & Sharpe Internal Grinding-wheel Spindle for Universal Grinding Machine

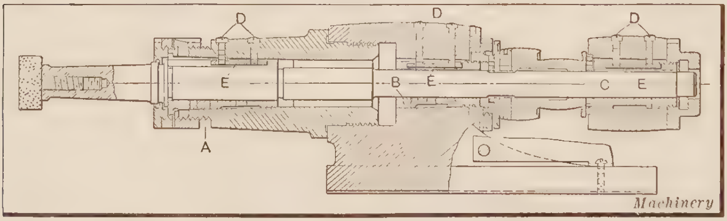


Fig. 6. Heald Internal Grinding-wheel Spindle

Heald Internal Grinding Spindle. — Fig. 6 shows one type of internal grinding spindle used on the Heald Nos. 70 and 75 internal grinding machines. The spindle is a solid shaft and is supported in three phosphor-bronze bearings *A*, *B*, and *C*. These are tapered on the outside diameter and adjusted by means of "take-up" nuts, as illustrated. The method of adjusting the bearing is to first tighten up a nut until the bearing fits the spindle snugly; then the screws *D*, which are threaded into tapered expanding blocks *E*, are adjusted, drawing up the blocks in the tapered slot in the bearings, and, in this way, slightly expanding them. This adjusting device provides a suitable and positive lock for the bearings and seats them securely and firmly in their housings.

Rivett Internal Grinding Spindle. — An internal grinding-wheel spindle designed to run at high peripheral velocities is shown in Fig. 7. This spindle is operated at speeds of from 25,000 to 30,000 R.P.M. with satisfactory results. The spindle *A*, which is of the solid shaft type, is driven by two belts running on pulleys located at each end and is supported by ball bearings, as shown. The bearings are completely submerged in oil supplied through screw-hole *B*. They are enclosed in a dust-proof cast-iron shell, adjustment being made by loosening screws *C* and turning adjusting nuts *D* with a spanner wrench, turning to the right to tighten and to the left to loosen. When properly adjusted, there should be no end play and the spindle should run freely when whirled by the fingers.

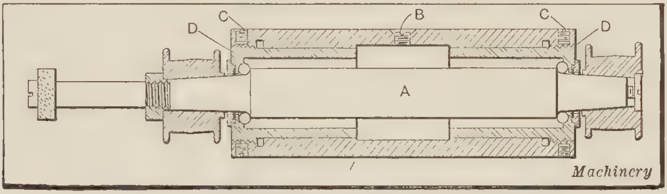


Fig. 7. Rivett Internal Grinding-wheel Spindle

Holding Work for Internal Grinding. — Next in importance, after selecting the right wheel to use on the internal grinding machine for a certain job, is the selection and construction of the chucking fixture for holding the work; in fact, there are many cases in which the chucking of the work is more important than the selection of the grinding wheel, because, where a difficult piece is to be held, more time may be required to satisfactorily chuck the piece and get it running right than it takes to grind it afterwards. This explains, to some extent, the difference in output and accuracy obtained in different shops operating on identically the same classes and kinds of work.

How to Hold Thin Bushings. — When grinding thin bushings, a special form of chucking device should be used, in which the bushing is clamped endwise, because any radial pressure, such as would result from using a 3-jaw chuck or similar arrangement, would distort the piece, so that after it was removed from the grinding machine, the hole would not be truly cylindrical. Very little clamping pressure is required to hold a bushing endwise, and these chucks can be made so that they are simple and quickly operated, thus producing work accurately and efficiently. There are two ways of grinding bushings; one is to grind the interior first and then slip them on an arbor and finish on a plain grinding machine; by this method accurate work is secured and the exterior and interior holes can be made truly concentric with each other. The other method is to grind the exterior of the bushing first, and then slip this into a holder or bushing chuck fitted to an internal grinding machine, and grind the hole last. While this may seem to be a very satisfactory method, in practice, it is not, for the following reasons:

1. It seems to be true that a bushing will change shape more when the inside is ground last than when ground first.

2. It is more difficult to grind the outside of a bushing to accurate limits, when the hole is rough and cannot be satisfactorily supported on a grinding arbor, than it is to grind the hole in the bushing first (the bushing being held by clamping endwise) and then slip the bushing on an arbor and finish the outside; the bushing, in this case, fits the arbor perfectly and has a good solid support for the grinding wheel at all points.

3. In fitting up a bushing chuck, it must be put onto the internal grinding machine spindle and be ground to size after being mounted, in order that the hole will run true. After one lot of bushings is finished, the chuck will be removed from the grinding machine and later replaced when another lot of bushings is to be handled. In making the second, third, and following replacements of the bushing chuck, the operator will

find it very difficult to get the chuck back on the grinding spindle and have the hole run "dead true"; therefore, he must either grind out the hole again to make it run true (and then the bushings are not a good fit), or else the subsequent lots of bushings must be ground to a larger diameter to fit the new diameter of hole in the chuck, all of which is avoided when the hole is ground first and the bushing finished externally last.

Grinding Cylindrical Holes. — Owing to the close limits of accuracy demanded of a grinding machine, it is often desirable to make some simple test to show that the machine is grinding perfectly straight. This can be determined when the hole is to size, by trying a sizing plug, and the operator can easily determine whether the hole is larger or smaller at the rear end than at the front end. There is a danger, of course, in testing the first pieces, that the machine may be grinding larger at one end than at the other, and if only the sizing plug is used in testing, it is impossible to tell, by this method, until the front end of the hole is up to size, whether the rear end is too large or not. Therefore, a very clever scheme is often resorted to, to determine if the hole is cylindrical or not. This is done by feeding the grinding wheel over to the opposite side of the hole after the latter has been roughed out by a few passes of the wheel and the original roughness of the hole removed. Now, if on bringing the grinding wheel against the opposite side of the hole and making a very light cut, the sparks are uniform throughout the length of the hole, the machine is grinding parallel or cylindrical, but if the sparks grow heavier as the wheel feeds in against the opposite side from where it has previously been grinding, the operator knows then that the hole is tapering and smaller at the back end. If the wheel fails to cut as it goes in, it shows that the hole is larger at the rear end, and the headstock should be correspondingly adjusted so that the hole will become more nearly straight. In carrying the wheel across to the opposite side of the hole from that to which it has been grinding, the error is doubled, so that if the headstock should have been set one degree out of correct alignment, the apparent error on the opposite side will be just double that.

Grinding Taper Holes. — In setting the headstock to secure the correct taper in a hole, the headstock may be set to the graduations provided on it, but if the work is desired to be very accurate and interchangeable with other parts, it will be most desirable to have a hardened standard plug gage with the correct taper on the end to use in testing the taper secured by this setting. In using this plug gage, the customary practice is to color it with prussian blue or red lead and note the contact that the ground hole makes on the plug; if it bears harder at the smaller end than at the larger end, the headstock should be swung so that the grinding wheel will produce a little less taper, and swung in the opposite way if the outer end should be tight and the hole loose at the small end of the plug. If the error is large, the operator can quickly feel that the plug does not fit the tapered hole properly. If the error is small, the testing by color will give satisfactory results.

Relation of Wheel to Work. — There are two methods of applying the wheel to the work for internal grinding. One is to feed the wheel against the rear side of the hole, and the other is to bring the grinding wheel forward to make a contact with the front side of the hole, the latter method being used on machines of the type built by the Heald Machine Co.

In using grinding attachments on universal grinding machines, since the automatic feed of the wheel would be toward the operator, it would be necessary to grind on the front side of the hole if this feed were used. According to the Brown & Sharpe Mfg. Co., the automatic feed is seldom used on their machines for internal grinding work; hence, it is the usual practice of this company to feed the wheel in the opposite direction and grind on the rear side of the hole. The Special Brown & Sharpe internal grinding machines are arranged for handling the work in this way. The principal advantage in grinding at the rear side of the hole seems to be, that, in grinding tapers, the headstock will be swung toward the operator, making it a little easier to see into the hole, and also easier to gage the hole with standard plugs. On the other hand, it appears to be less easy to protect the operator from the splashing of the water and also to keep the water from being thrown over the front of the machine and on the floor, when tapers of high degree are being ground, it being much easier to arrange water guards at the rear of the machine than at the front. While the operator can become accustomed to feeding the wheel away from him, this is an opposite direction to which all plain grinding and universal grinding machines naturally operate, and, therefore, by some manufacturers, it has been thought more natural to do the grinding on the front side of the hole.

Another difficulty in connection with grinding on the rear side of the hole, is that, in truing the wheel, the diamond should, preferably, be mounted at the back of the wheel, so as to operate on the rear side, *i.e.*, true the wheel on the side that does the grinding; this would appear to be a trifle more awkward for the operator than when the grinding is done on the front side of the hole and the diamond can be mounted on the front side.

In regard to the direction of rotation of the work, it is customary, with almost all manufacturers, to have the work head rotate so that the top comes toward the operator. In grinding dry, it does not matter particularly in regard to the direction of rotation, but when water is used, rotation of the work in this direction seems to assist in the proper control of the water, particularly where it flows out from the bottom of the chuck and water guards.

The two methods of applying the wheel to the work are shown diagrammatically in Fig. 8. At *A* is shown the method generally followed on a universal grinding machine, whereas at *B* is shown the method that is adopted generally on regular internal grinding machines. The natural position of the wheel in relation to the work for internal grinding is on the front face of the hole. For instance, when using a universal grinding machine for external cylindrical grinding, the wheel is fed forward to grind the work, and it is natural, when using an internal attachment, that the same method of feeding the wheel to the work be followed.

Allowances for Internal Grinding. — The amount of metal to be removed by the internal grinding machine requires careful consideration. Formerly, when light grinding spindles and relatively light machines only were available, it was desirable to leave as little stock for grinding as possible, to reduce the time required for grinding. With the modern internal grinding machine, however, this is not true, and it is now considered wiser to leave a liberal amount of stock to be removed, as this somewhat reduces the high degree of accuracy that would be necessary in chucking the pieces if but a small amount of stock was left to be ground out.

For instance, suppose a bushing is to be finished externally after the hole is ground. This bushing, if it has thin walls, should be held in a special bushing chuck, but if it has heavy walls, it might be held in a 3-jaw chuck, and, in that way, would only run approximately true. The hole might run out 0.002 or 0.003 inch. Under such conditions, the first thing to do is to get the hole rounded out so that it runs practically true, and in doing this, of course, more stock will be ground off one side of the hole than the other. This would involve the grinding out of 0.006 or 0.007 inch of stock by the time the hole was running true, and if there were 0.002 or 0.003 inch left to grind to get the exact diameter, there would be from 0.008 to 0.010 inch stock to remove from this hole during the grinding operation.

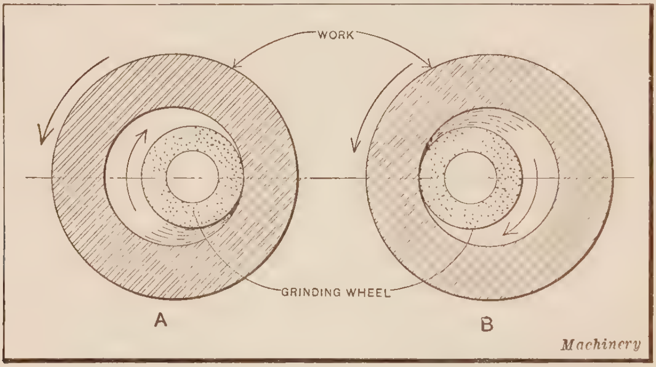


Fig. 8. Diagram illustrating Relation between Wheel and Work for Internal Grinding

It is now considered more satisfactory, with the modern internal grinding machine, to leave an ample amount of stock, so that the wheel can take heavy cuts, than to leave a small amount of stock and make it necessary to take several very light cuts to true the hole, because there is such a limited amount of stock. On the other hand, if work is accurately machined and the chucking fixture is one that is not only accurate to begin with but remains accurate, so that the holes run quite true, then the stock to be removed can be reduced to advantage and a considerable saving in time effected. The tendency is, in many cases, however, to reduce the stock to a point where the operator has to grind slowly at first because the hole is not running true, whereas he would actually make a greater gain in time and quality of work if a little more stock were left, provided he has a modern manufacturing machine to work with.

With hardened parts, of course, there is the question of distortion, and, oftentimes, the distortion due to hardening makes it necessary to leave more stock than would otherwise be necessary. One reason why records on similar work in different shops vary so greatly is because of the difference in the way the work comes to the grinding machine, so far as the previous machining operations are concerned, and, secondly, owing to the difference in chucking devices and methods of holding the work adopted in different factories.

The following is an example which illustrates the relation of the amount of material removed to wheel wear. An extended experiment was made in the grinding of a tapered hole in a pinion blank. These pinion blanks were made from vanadium-steel drop-forgings, heat-treated, and were drilled and reamed so that 0.015 inch was left on the diameter for grinding. Various grains and grades, as well as makes of wheels, were tried, and the greatest number of pieces that could be obtained from one wheel was sixty. The limit of allowance was then reduced from 0.008 to 0.010 inch on the diameter and the production from one wheel increased to eighty. The limit was again reduced to 0.005 inch on the diameter, whereupon the production increased to two hundred pieces from one wheel. The wheel found to give the best results on this particular example was a Norton alundum (vitrified), grain 60, grade K wheel, $\frac{3}{4}$ inch in diameter by 1-inch face. This wheel was operated at a speed of 12,500 R.P.M. (2460 feet surface speed) and the work was rotated at 400 R.P.M., or an average surface speed of 100 feet per minute. Table I gives the amounts to leave for grinding holes of various diameters and lengths, but does not take into consideration special cases, such as thin wall bushings, etc.

Wheel and Work Speeds for Internal Grinding. — The cutting efficiency of grinding wheels depends largely upon the wheel and work speeds. To obtain theoretical speed at which any particular wheel should be operated is not always practicable, because of the limitations of the machine on which the wheel and wheel-spindle is mounted, thus making compromises necessary to a certain extent. For instance, when using a wheel $\frac{1}{2}$ inch in diameter, a wheel speed of about 30,000 R.P.M. would be necessary to get a surface velocity of 4000 feet per minute. While this speed might be possible in certain machines, ordinarily, lubrication difficulties and heating due to such a high speed would overbalance the advantages. Since modern

Table I. Allowances for Internal Grinding

Diameter of Hole in Inches	Length of Hole in Inches									
	½	1	1½	2	3	4	5	6	7	8
	Allowance in Inches									
½	0.005	0.006	0.007	0.008	.....	.....	.....	.....	.....	....
1	0.006	0.007	0.008	0.009	0.010	0.011	0.012	0.013	.....	.....
1½	0.007	0.008	0.009	0.010	0.011	0.012	0.013	0.014	0.015	0.016
2	0.008	0.009	0.009	0.010	0.011	0.012	0.013	0.015	0.016	0.017
2½	0.009	0.010	0.010	0.011	0.011	0.013	0.014	0.015	0.017	0.018
3	0.009	0.010	0.010	0.011	0.012	0.013	0.015	0.016	0.017	0.019
3½	0.010	0.010	0.011	0.012	0.013	0.014	0.015	0.017	0.018	0.019
4	0.010	0.011	0.012	0.012	0.013	0.015	0.016	0.017	0.018	0.020
5	0.011	0.012	0.013	0.013	0.015	0.016	0.017	0.018	0.019	0.021
6	0.012	0.013	0.014	0.014	0.016	0.017	0.018	0.019	0.020	0.022
7	0.014	0.015	0.015	0.016	0.017	0.018	0.019	0.020	0.021	0.023
8	0.016	0.016	0.017	0.017	0.018	0.019	0.020	0.021	0.022	0.024
9	0.017	0.018	0.018	0.019	0.020	0.020	0.021	0.022	0.023	0.025
10	0.018	0.019	0.019	0.020	0.021	0.021	0.022	0.023	0.024	0.025
11	0.019	0.020	0.020	0.021	0.022	0.022	0.023	0.024	0.025	0.026
12	0.020	0.021	0.021	0.022	0.023	0.023	0.024	0.025	0.026	0.027

grinding wheels can be obtained which will cut efficiently, rapidly, and smoothly at slower speeds (by selecting the proper grain and grade), it will be found, in almost every instance, that moderate speeds will be more satisfactory, because less care will be needed in oiling and adjustment of the bearings and no reduction in the actual amount of work produced need be expected. On the other hand, wheelheads adapted for carrying grinding wheels of 2 inches in diameter and larger can be run at the speeds which will bring the circumferential velocity up to what is usually considered theoretically correct, and the foregoing remarks apply, as will be readily understood, to wheels of relatively small diameter used in grinding machines having a large range of work.

In the examples of work which were observed to obtain definite information on this point, the wheel speeds used ranged from 1570 to 7035 feet surface speed, whereas the work speeds varied from 29.5 to 510 feet surface speed. The only reason that can be given for such wide variations in wheel and work speeds is that the subject of correct wheel and work speeds has not been given sufficient attention. It was found that one manufacturer was satisfied with a hard-bond, fine-grain wheel and a low production, as long as he obtained a good finish, whereas another manufacturer was more interested in production than finish, and, consequently, used a coarser grain wheel of softer bond. For internal grinding of soft steel, a harder bond wheel than M is seldom used, whereas for heat-treated steel, a wheel harder than grade L is uncommon. For chrome-nickel or chrome-vanadium steel, heat-treated, grade K is about the hardest wheel used.

It can be definitely stated, that, in most cases, the lower the wheel speed and the harder the bond of the wheel, the higher must be the work speed to get satisfactory results. When using a hard-bond wheel, glazing takes place unless the work speed is high enough to remove the abrasive grains from the bond as soon as they become dull; therefore, it is always advisable to have the wheel speed correct, and then vary the grade and grain of the wheel and the work speed until satisfactory results are obtained. Wheel speeds for internal grinding are found to vary all the way from 2000 to 7000 feet surface speed; but the most satisfactory wheel speeds are between 4000 and 6000 feet surface speed. As a rule, grinding wheels made from such abrasives as carbolite, carborundum, or crystolon are operated at lower wheel speeds than grinding wheels made from abrasives such as alundum, aloxite, or corundum. For grinding wheels made from carbolite, carborundum, or crystolon, the most suitable wheel speeds range between 4000 and 4500 feet surface speed, whereas for wheels made from alundum, aloxite, or corundum, the most suitable speeds are between 4500 and 5000 feet surface speed. Table II gives the equivalent R.P.M. of wheels ranging from $\frac{1}{4}$ to 4 inches in diameter operating at surface speeds ranging from 2000 to 6000 feet surface speed.

Table II. Revolutions per Minute for Various Surface Speeds of Wheels

Diameter of Wheel in Inches	Surface Speed in Feet per Minute							
	2000	2500	3000	3500	4000	4500	5000	6000
	Revolutions per Minute							
¼	30,558	......	......	......	......	......	......	.....
⅜	20,372	25,465	30,558	......	......	......	......	.....
½	15,279	19,099	22,918	26,738	30,558	......	......	.....
⅝	12,221	15,279	18,335	21,390	24,442	27,500	30,558	.....
¾	10,186	12,733	15,279	17,825	20,372	22,918	25,465	30,558
⅞	8,731	10,913	13,096	15,279	17,461	19,643	21,827	26,192
1	7,639	9,549	11,459	13,369	15,279	17,189	19,099	22,918
1¼	6,111	7,639	9,167	10,695	12,221	13,750	15,279	18,335
1½	5,093	6,366	7,639	8,913	10,186	11,459	12,733	15,279
1¾	4,365	5,457	6,548	7,639	8,731	9,822	10,913	13,096
2	3,820	4,775	5,729	6,684	7,639	8,594	9,549	11,459
2¼	3,395	4,244	5,093	5,942	6,791	7,639	8,488	10,186
2½	3,055	3,820	4,583	5,347	6,111	6,875	7,639	9,167
2¾	2,778	3,472	4,167	4,861	5,555	6,250	6,945	8,334
3	2,546	3,183	3,820	4,456	5,093	5,729	6,366	7,639
3½	2,182	2,728	3,274	3,820	4,365	4,911	5,457	6,548
4	1,910	2,387	2,865	3,342	3,820	4,297	4,775	5,729

The correct speed at which the work should rotate cannot be decided absolutely, owing to varying conditions. There are a few points, however, that are worthy of consideration. For instance, the work should not run at the same speed for grinding a 3-inch hole as it would for grinding a 1-inch hole.

The reason is that the higher surface speed of the work with the larger hole tends to break down the working face of the wheel, and, consequently, a wheel of harder grade is necessary than if the work speed were moderate. It is also true that the hard wheel does not cut as freely as the softer wheel, and, therefore, the time required for grinding may actually be longer than would be the case with a moderate speed and a freer cutting wheel.

Table IV gives what might be called the average surface speeds for grinding various materials when using grinding wheels of the grades and grains listed. As has been previously mentioned, the relation of the diameter of the hole to the diameter of the wheel has a considerable bearing on the work speed. The speeds given in the table can be used as a basis upon which to start. For the average internal grinding operation, the work speeds range from 75 to 125 feet per minute, the average being in the neighborhood of 100 feet surface speed. Table III gives a list of the equivalent R.P.M. for various diameters of holes and work speeds.

Table III. Revolutions per Minute for Various Surface Speeds of Work

Diameter of Work in Inches	Surface Speed of Work in Feet per Minute								
	60	70	80	90	100	110	120	130	140
	R.P.M. of Work								
⅜	611.0	713.0	815.0	916.0	1018.0	1121.0	1222.0	1323.0	1425.0
7/16	524.0	611.0	699.0	786.0	873.0	961.0	1049.0	1136.0	1222.0
½	459.0	535.0	611.0	688.0	764.0	840.0	917.0	993.0	1070.0
⅝	367.0	428.0	489.0	552.0	611.0	673.0	736.0	796.0	857.0
¾	305.0	357.0	408.0	458.0	509.0	559.0	611.0	661.0	711.0
1	229.0	267.0	305.0	344.0	382.0	420.0	458.0	497.0	535.0
1¼	183.0	214.0	244.0	274.0	305.0	337.0	367.0	398.0	428.0
1½	153.0	178.0	204.0	230.0	254.0	279.0	305.0	330.0	356.0
1¾	131.0	153.0	174.0	196.0	218.0	240.0	262.0	283.0	305.0
2	115.0	134.0	153.0	172.0	191.0	210.0	229.0	248.0	267.0
2¼	102.0	119.0	136.0	153.0	170.0	187.0	204.0	221.0	238.0
2½	91.7	107.0	122.0	138.0	153.0	168.0	184.0	199.0	213.0
2¾	83.4	97.2	111.0	125.0	139.0	153.0	167.0	181.0	195.0
3	76.4	89.1	102.0	114.0	127.0	140.0	153.0	165.0	178.0
3½	65.5	76.4	87.4	98.1	109.0	120.0	131.0	142.0	153.0
4	57.3	66.9	76.4	86.0	95.6	105.0	115.0	124.0	134.0

Width of Face of Grinding Wheels. — Various automobile manufacturers and other concerns throughout the country have adopted different widths of wheels for internal grinding, ranging all the way from ¼ to 2 inches. The Reo Motor Co., Lansing, Mich., after several years of experimenting with different widths of wheels, has found, that for ordinary plain internal grinding on holes larger than 1 inch, a grinding wheel with a ¾-inch face gives the best results. This width of face of wheel is used exclusively on all internal work over 1 inch and under 3 inches in diameter that is not provided with grooves or keyways. For a considerable length of time, wheels of ½-inch face were used, but it was found that these did not have sufficient cutting surface or width of face to remove the metal efficiently. On the other hand, it was found that, with a wheel wider than ¾ inch, there was too much wheel surface in contact with the

Table IV. Work Speeds in Feet per Minute for the Internal Grinding of Different Materials*

Material	Abrasive	Bond	Grain	Grade	Surface Speed of Work
Aluminum (Cast)	Carbolite,	Elas.	46 to 50	2½ E	150 to 180
	Carborundum,	Vit.	50	P	
	or Crystolon	Elas.	36	2½	
Brass or Bronze (Cast)	Alundum,	Vit.	36 to 46	K	130 to 150
	Corundum,		46 to 50	K	
	or Aloxite		46 to 50	O	
Iron (Cast)	Carbolite,	Vit.	36 to 40	K	110 to 120
	Carborundum,			P	
	or Crystolon			K	
Alloy Steel, Heat-treated	No. 38 Alundum,	Vit.	46	J	80 to 100
	No. 58 Corundum,		46	J	
	or Aloxite		50	M	
Steel, 0.20 to 0.50 Per cent Carbon (Soft)	No. 38 Alundum,	Vit.	46	J	60 to 80
	No. 58 Corundum,		46	J	
	or Aloxite		50	M	
Steel, 0.20 to 0.50 Per cent Carbon (Hardened)	No. 38 Alundum,	Vit.	46	K	80 to 110
	No. 58 Corundum,		46	K	
	or Aloxite		50	M	

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* Work speeds based on from 4500 to 5000 feet surface speed for alundum, aloxite, and corundum wheels, and from 4000 to 4500 feet for carbolite, carborundum, and crystolon wheels.

work and trouble was experienced with heating of the work. For the finishing of small internal holes less than 1 inch in diameter, it was found that a Detroit wheel $\frac{7}{8}$ or $\frac{3}{4}$ inch in diameter, $\frac{1}{4}$ inch wide, grain 67, grade M, gave the best results. This wheel was used exclusively on hardened work, as the greater portion of the work turned out by this company is low carbon steel, carbonized and hardened.

For grinding holes in which keyways are cut, a narrow face wheel cannot be used with success, because it does not present sufficient wheel surface to the work in order to stand up for any length of time. The greater the number of splines or keyways, as a rule, the harder the wheel must be. For this class of work, the Reo Motor Car Co. used a wheel with a $1\frac{1}{8}$-inch face on holes up to 2 inches in diameter, and for larger work, a wheel of $1\frac{1}{2}$-inch face. A wheel which has been found to give excellent results on this work is a Norton (vitrified) No. 38 alundum wheel, grain 60, grade M and N. Such wide wheels are used only on internal grinding machines especially designed for manufacturing.

Relation between Diameter of Wheel and Hole. — Usually, in ordering grinding wheels for internal work, especially for grinding holes less than $1\frac{1}{2}$ inch in diameter, the wheel is specified to be about the same diameter as the hole in the work, and is then turned down with a diamond until it enters the hole with a reasonable amount of clearance. Theoretically, this is not the most efficient diameter; wheels of this size are ordered for economic reasons. The larger the diameter of the wheel in relation to the hole in the work, the larger is the arc of contact and the greater the tendency to glaze and heat the work. In addition to a greater arc of contact, a wheel used for internal grinding has less body or volume to carry out the heat generated and will heat up and glaze much quicker than a wheel used externally. Usually, wheels for internal grinding are used until completely worn out. Wheels are ordered as large as possible, in order that the greatest possible number of pieces may be turned out with one wheel, thus reducing wheel expense. From a purely theoretical standpoint, however, the smaller the diameter of wheel in relation to the hole in the work, the less will be the arc of contact and the higher will be the cutting efficiency of the wheel.

Preventing Chatter. — Chatter marks in internal grinding are generally caused by using a wheel that is too hard, taking too heavy a cut, or by using a grinding spindle with the bearings out of adjustment and slenderly supported. Great care should always be taken to keep the spindle bearings correctly adjusted, so that there is no play or end shake of any kind, as this is bound to produce chatter and tends to make the ends of the hole "bell-mouthed." Work provided with keyways or splines is difficult to grind true and free from chatter marks, and special care should be taken to see that all bearings of the machine are tight. The same applies to the bearings of the work head. Having the wheel run out of true will also cause chatter and will produce a roughened surface on the work. It is, therefore, necessary to keep the wheel true and sharp.

Inaccurate holes are also caused by having the wheel-spindle too loose or by putting excessive clamping strains on the work so as to spring it out of shape; using a wheel that is too hard also produces the same result, in some cases. All other factors being considered, a soft wheel will grind a truer hole than a wheel which is comparatively hard.

Wet vs. Dry Grinding. — Internal grinding is generally done dry in the tool-room, but when grinding duplicate parts in connection with manufacturing, cooling water is often used. The general practice, in regard to the use of water for internal grinding, is to grind soft and hardened steel work wet, and to grind cast iron, bronze, and brass dry. There are, of course, exceptions to this rule, and sometimes work that is hardened is of such a shape that the use of water is either inconvenient or not necessary. For instance, when the surface to be ground is narrow and a small amount of stock is to be removed in proportion to the size of the work, the grinding can be done without any appreciable change in temperature. As a general rule, however, soft and hardened steel parts should be ground wet. Wet grinding produces a smoother and truer hole than dry grinding, and also facilitates gaging. Where a part has been heated to a considerable extent by grinding and a cold gage is placed in it, the gage is likely to "freeze," and difficulty will be experienced in removing it. Minute cracks in the surface of the work are also likely to develop in dry grinding, especially when a wheel of too fine a grain and too hard a bond is used, or where too heavy a cut is taken. A further reason for wet grinding is that it is impossible for the operator to know just what size the hole will be, if the work has warmed up 20 or 30 degrees during the grinding, after it has been removed from the machine and has cooled down to the normal temperature. On interchangeable work and where accurate limits must be maintained, wet grinding is, therefore, imperative.

There are cases where cast-iron parts should be ground wet. When the work must be ground to very accurate limits, water has to be used to keep down the temperature, in order to prevent any change of diameter or shape. This applies more particularly to the grinding of thin, cast-iron bushings. It has been found that a cast-iron bushing, ground dry, will spring out of shape, to some extent, after it is taken out of the machine. By keeping the part at a uniform temperature, by means of a cooling lubricant, any change in diameter and shape is avoided. When grinding cast-iron cylinders, it is common practice to circulate cooling water through the jacket instead of in the bore, as explained more fully in Chapter IV. When dry grinding is done, it is necessary to provide the machine with an exhaust system to draw off the dust, both for the protection of the operator and to keep the machine clean and in a satisfactory working condition.

Cause of Bell-mouthed Holes. — Bell-mouthed holes may be caused by looseness in the spindle or by completely removing the wheel from the hole at each traverse. The wheel should never be withdrawn from the work except when it is necessary to remove it to gage the hole. While the power traverse is being used for advancing and withdrawing the wheel, the wheel should never pass clear through the work, but about one-half of the wheel surface should still remain in the hole. The reason for this is that, when the wheel is withdrawn, any slackness in the spindle tends to throw it out to one side because the strain of cutting has been removed; consequently, the hole is made bell-mouthed.

Examples of Internal Grinding. — The typical examples of internal grinding shown in the following illustrations, indicate, in a general way, how various classes of work are ground. The nature of each operation is indicated by a simple diagram, beneath which the grain and grade of the wheel, the speed of both wheel and work, and other important information is given to serve as a guide when grinding other parts of the same general class. Many of these examples are self-explanatory and will not be referred to in detail.

Grinding Ball Races. — Ball races for spherical balls are made in two principal shapes: One is the V-groove type, and the other, the semi-circular. To finish a ball race of the V-groove type, it is necessary to form the wheel and keep it trued to the desired shape. Usually, in grinding this type of race, roughing and finishing operations are done at the same setting, a grinding wheel being selected that gives fairly good results for both operations.

Where the ball race is of the semicircular type, a formed wheel, sometimes held on a regular internal grinding machine spindle, is used for roughing out the groove, and the finishing is done in another machine of the radial type. The allowance left for finish-grinding varies from 0.002 to 0.008 inch, depending on the size of the bearing.

A radial grinding machine of the Van Norman type is shown in Fig. 9 arranged for finish-grinding a ball race. Assume that an outer race having a ball circle of $1\frac{1}{2}$ inch in diameter is to be ground as shown in Fig. 10. For making the traverse setting of the work-holding head, a plug exactly 0.750 inch long is placed between stops *A*, Fig. 9, the slide being adjusted until both stops engage with the plug. The cross-slide of the work head is then locked in this position.

The next step is to move the work head back the required distance longitudinally so that the radial center of the race is exactly over the pivoted point about which the head oscillates. For this purpose, the shoulder near the front end of the spindle is taken as a reference point, which, as shown in Fig. 10, is 1.625 inch from the center of the ball race. This adjustment is made by placing a plug exactly 1.625 inch long between the stops located on the rear side of the longitudinal slide of the work head.

Next, the grinding wheel is located over the center-line of the work, as shown to the left in Fig. 10. The wheelhead is mounted on a slide which is moved back and forth by a hand-operated rack and pinion, and to make this setting, stop *C*, Fig. 9, which bears against the frame, is adjusted to the proper point and locked. In order to true the wheel, the work head is moved around to the central position, where a plunger *D* enters a hole on the swivel-slide support, holding the truing device securely in place. In this position, the post *E*, upon which the diamond holder is mounted, is properly located.

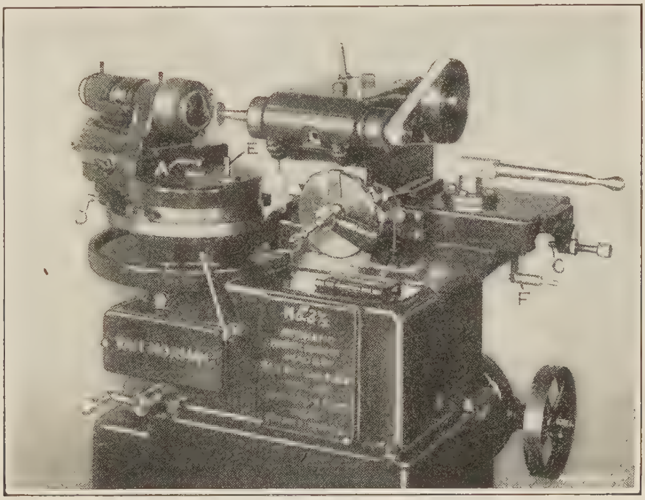


Fig. 9. Van Norman Automatic Radial Grinder for Grinding Single-row Ball Bearings

The distance between the axis about which the work head oscillates and the center of the stud, upon which the truing device is mounted, is approximately 3 inches. Therefore, in order to true the wheel, it is necessary to move it back to the diamond point, which is accomplished by means of distance plug *F*. In starting to true the wheel, the wheel slide is moved back a distance slightly greater than 3 inches, after which the distance plug *F* is swung into position and the slide moved forward to bring the stop *C* into contact with it. A detail view of the wheel-truing device is shown at *A* in Fig. 10. Means for setting the diamond holder for truing wheels of different radii is provided for by different size disks *a* held on a plunger *b*. The diamond is brought in contact with a disk of the proper size and the holder clamped in position.

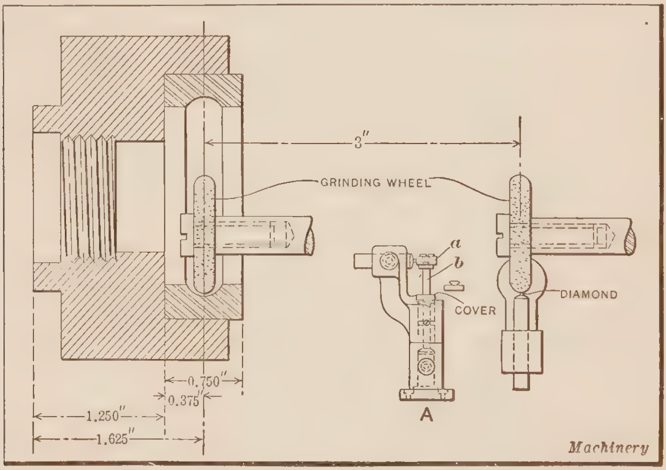
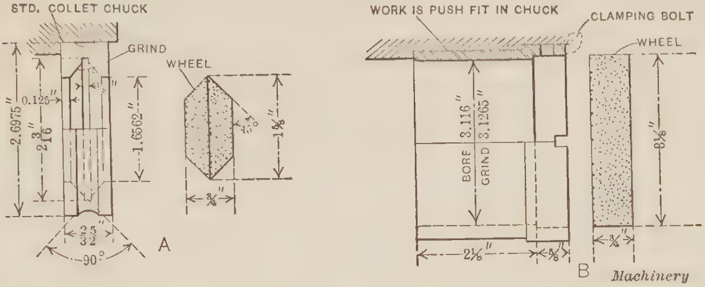


Fig. 10. Diagram showing Method of setting and truing Wheel on Van Norman Radial Grinding Machine

Surface Cracks when Grinding Ball Races. — In grinding ball races, trouble is sometimes experienced with minute cracks developing in the surface of the work. Many reasons have been given for this, but the most plausible one is that the exterior surface of the work is sometimes heated so rapidly that the elastic limit of the metal is exceeded before the heat has time to dissipate. This may be caused by using a wheel of too fine a grain and too hard a bond; forcing the wheel beyond its cutting capacity; using a wheel that has become glazed and is not free cutting; grinding dry. Strains set up in hardening are a con-



Machinery

A

Work: — Double cone race internally form ground; material, 0.15 per cent carbon, open-hearth steel, carbonized 0.030 inch deep, and hardened.

Operation: — Grinding internal ball race with Norton (vitrified) alundum, combination grain wheel; grain 38–60, grade J, 1⅝ inch by ¾ inch; speed, 10,600 R.P.M. — 4500 feet surface speed; work speed, 400 R.P.M. — 170 feet surface speed; material removed, from 0.010 to 0.020 inch on diameter.

Remarks: — Grinding wheel moved in until both sides touch, then fed directly into work by operating cross-feed by hand; 50 pieces ground for each truing of wheel; production, 300 pieces in nine hours; machine used, No. 75 Heald internal grinding machine.

B

Work: — Sleeve, 0.15 per cent carbon, open-hearth steel; carbonized 0.030 inch deep, and hardened.

Operation: — Grinding internal diameter with Norton (vitrified) alundum wheel, 3⅛ inches by ¾ inch, grain 36, grade J; speed, 8600 R.P.M. — 7035 feet surface speed; work speed, 400 R.P.M. — 327 feet surface speed.

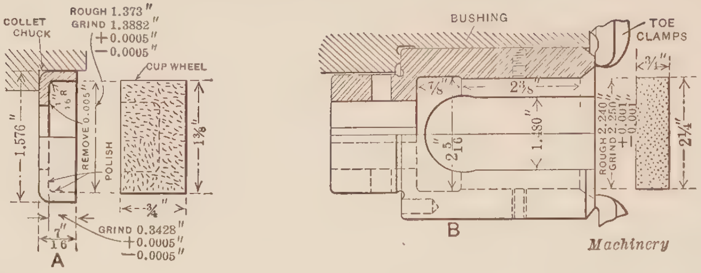
Remarks: — Wheel traversed by power for roughing, 55 inches per minute; for finishing, 18 inches per minute; six traverses to complete work; production, 75 pieces in nine hours; Heald internal grinding machine.

Fig. 11. Internal Grinding Operations on a Ball Race and a Sleeve

tributory cause to grinding cracks, and, as a remedy, it has been suggested to let the work season for some time after hardening and before grinding.

The grain and grade of grinding wheel to use is determined largely by the character of the work and the treatment it receives. As a rule, for grinding hardened ball races, it is not advisable to use a wheel of a bond much harder than *J*. A combination of different size grains in the wheel is also preferable to a "straight-grain" wheel, as the combination-grain wheel holds its shape much longer. Another way to obviate grinding cracks is to keep the wheel free cutting and not force it beyond its cutting capacity.

Grinding a V-shape Ball Race. — An example of ball-race grinding of the V-type is shown at *A* in Fig. 11. In grinding



Machinery

A

Work: — Cup for fan shaft bearing, No. 12 Birmingham wire gage (0.109 inch thick) pressed steel, carbonized 0.030 inch deep and hardened in oil.

Operation: — Grinding inside back face and internal diameter with a Norton (vitrified) alundum cup-shaped wheel, grain 46, grade K; 1⅜ inch diameter, ¾ inch face; speed, 17,660 R.P.M. — 6360 feet surface speed; work speed, 740 R.P.M. — 266 feet surface speed; amount removed, 0.005 inch from back inside face, and 0.015 inch from internal diameter.

Remarks: — Grinding wheel is brought in to finish bottom first, and in doing so also grinds the internal diameter. To finish internal diameter, wheel is traversed. To get a good polish, machine oil is squirted in the hole just as the wheel is finishing it. Wheel must not wear down much below full diameter of hole, and one wheel turns out 100 pieces; production 225 to 230 pieces in nine hours; machine used, Lansing Stamping & Tool Co. internal grinding machine.

B

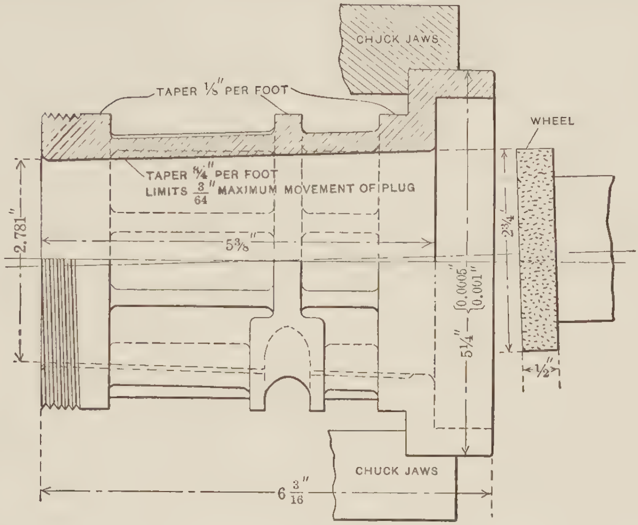
Work: — Universal transmission drive shaft yoke, 0.15 per cent carbon open-hearth steel; carbonized 0.030 inch deep, and hardened.

Operation: — Grinding hole which is partly cut away on both sides with a Norton (vitrified) alundum wheel, grain 36, grade K; 2¼ inches diameter, ¾ inch face; speed, 7200 R.P.M. — 4240 feet surface speed; work speed, 216 R.P.M. — 154 feet surface speed; amount removed from diameter, 0.010 to 0.015 inch.

Remarks: — Power traverse is used at the rate of 65 linear inches per minute, twenty-four traverses being required to complete work; production, 160 in nine hours; machine used, No. 70 Heald internal grinding machine.

Fig. 12. (A) Grinding Back Face and Internal Diameter of Bearing Cup. (B) Grinding Hole having Slotted Sides

this race, the wheel is located by bringing it slowly in until it touches both sides of the V-shape race. Then the traverse motion of the grinding wheel slide is stopped and the wheel slide advanced toward the operator, or, in other words, the wheel is fed directly in on the work until the approximate diameter is reached. The wheel is then withdrawn and the work gaged. This continues until the ball race has been ground to the correct diameter. In order to obviate the frequent withdrawal of the wheel to gage the work, the micrometer collar on the wheel operating slide screw is used. The race is measured by an internal caliper type of gage furnished with ball ends. A combination grain, soft-bond wheel is used for this work. The combination of grain in the wheel enables a greater number of



Machinery

Work: — Front spindle box made from phosphor-bronze casting.

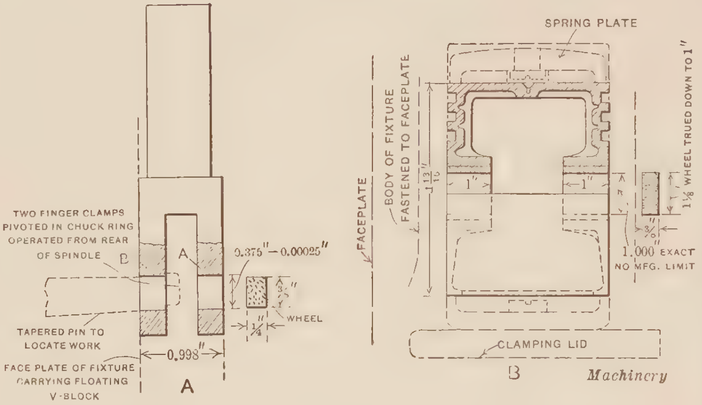
Operation: — Grinding internal diameter of taper bearing with a Norton (elastic) alundum wheel, grain 46, grade 1/4; 2 3/4 inches diameter, 1/2 inch face; speed, 5555 R.P.M. — 4000 feet surface speed; work speed, 198 R.P.M. — 150 feet average surface speed; amount removed from 0.010 to 0.012 inch.

Remarks: — Wheel is traversed by power at the rate of 48 linear inches per minute; production, 3 per hour; machine used, No. 22 Brown & Sharpe internal grinding machine.

Fig. 13. Internal Grinding Operation on Phosphor-bronze Spindle Bearing

pieces to be turned out for each truing of the wheel, as it holds its shape much better than a straight-grain wheel.

Grinding a Cup-shaped Bearing. — The example of internal grinding shown at *A* in Fig. 12 is a cup for a fan-shaft bearing; it is made from sheet steel formed into shape, then carbonized and hardened in oil. The hole must not only be true and accurate, as regards size, but must be smooth and free from scratches. The cup-shape wheel used is fed in until it touches the bottom of the hole and this surface is ground first. The action of forcing the wheel against the bottom throws the spindle slightly out of line, and, consequently, the internal diameter is also ground. Allowance is made for this on the work, so that, by the time the desired amount is removed from the bottom, the hole is practically ground to size.


TWO FINGER CLAMPS PIVOTED IN CHUCK RING OPERATED FROM REAR OF SPINDLE
B
A
0.375"−0.00025"
3/8"
WHEEL
1/4"
TAPERED PIN TO LOCATE WORK
0.998"
FACE PLATE OF FIXTURE CARRYING FLOATING V-BLOCK
A
SPRING PLATE
FACEPLATE
BODY OF FIXTURE FASTENED TO FACEPLATE
1 13/16"
1"
1"
3/8"
1.000" EXACT NO MFG. LIMIT
1 1/8" WHEEL TRUED DOWN TO 1"
CLAMPING LID
B
Machinery

A

Work: — Valve lifter, 0.20 per cent carbon steel, casehardened.

Operation: — Grinding cross holes with a Norton (vitrified) alundum wheel, grain 60, grade M, 3/8 inch diameter, 1/4 inch face; speed, 16,000 R.P.M. — 1570 feet surface speed; work speed, 300 R.P.M. — 29.5 feet surface speed; amount removed from diameter, 0.004 to 0.005 inch.

Remarks: — Work is first accurately located by tapered centering plug, then wheel is fed in by hand and hole (A) is first ground to within 0.001 inch of finished size. Hole (B) is then ground likewise. Then both holes are ground to gage size. (See illustration for limits.) Production, 150 pieces per hour. Machine used, Rivett internal grinding machine.

B

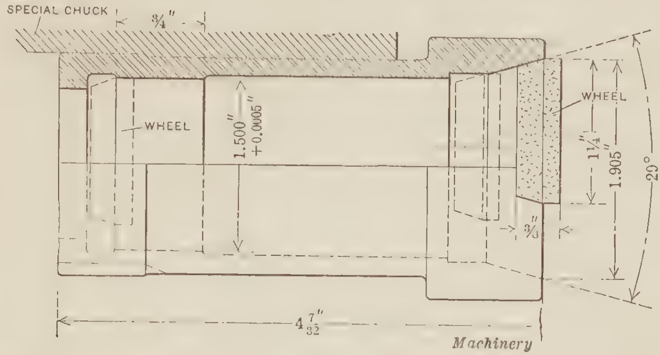
Work: — Automobile gas engine piston made from iron casting.

Operation: — Grinding wrist-pin holes which have been bronze bushed, with a Norton (vitrified) crystolon wheel, grain 60, grade J, 1 1/8 inch diameter, 3/8 inch face; speed, 14,000 R.P.M. — 3660 feet surface speed; work speed, 434 R.P.M. — 114 feet surface speed; amount removed from diameter, 0.010 inch.

Remarks: — Piston is held in a special fixture and is located from the open end by a spring pad. It is lined up with the grinding wheel spindle by a plug and clamped. Hand traverse is used; production, 3 minutes for each piston; machine used, No. 70 Heald internal grinding machine.

Fig. 14. (A) Grinding Cross Holes in Valve Lifter. (B) Grinding Wrist-pin Hole of Gas Engine Piston

The wheel must be kept to approximately the same diameter, and it requires a large number of wheels to turn out a large quantity of work. The reason for this is that, as soon as the wheel is worn down much smaller than the diameter of the hole, it produces cross marks on the bottom or inner face, which are objectionable on this job. Just as soon as the grinding wheel finishes the internal diameter to size, a small amount of lard oil is squirted onto the work. Then, when the wheel is passed back and forth a couple of times, the result is an excellent polish. While it is not advisable, as a rule, to use oil on a grinding



Work: — Spring collet sleeve for automatic screw machine made from tool steel, hardened.

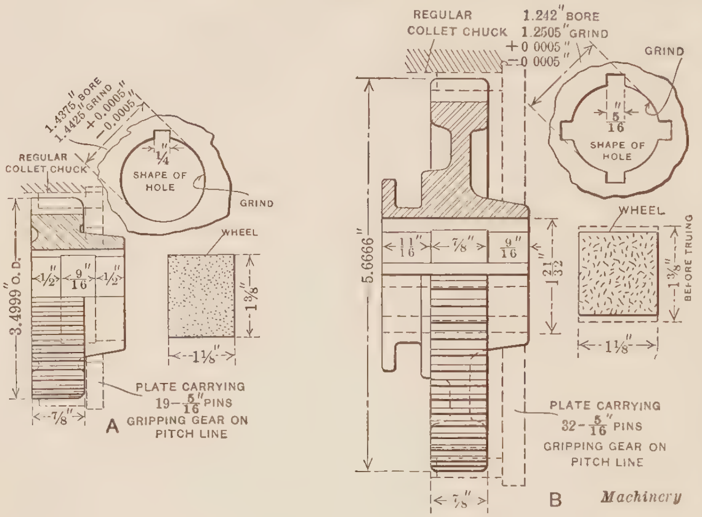
Operation: — Grinding straight and tapered holes with a Norton (alundum) wheel, grain 38–80, grade J; 1¼ inch diameter, ⅜ inch face; speed, 11,600 R.P.M. — 3800 feet surface speed; work speed, 225 R.P.M. — 100 feet average surface speed; amount removed from diameter, 0.010 inch on straight portion, and 0.012 inch on tapered portion.

Remarks: — For grinding straight hole the table is traversed by power at 48 linear inches per minute; for grinding tapered portion, the wheel-slide is set off at an angle and the wheel is brought in by hand power; production, 4 per hour; wheel is not trued up at all after first truing; machine used, No. 2 Brown & Sharpe universal grinding machine.

Fig. 15. Example of Internal Grinding on Cylindrical and Taper Surface

wheel because of the glazing effect, in this case, it produced the results desired. As soon as this same wheel strikes a rough piece, all the glazing effect is removed, so that it is not necessary to dress the wheel until it is worn down too small.

Grinding Holes Having Keyways or Slots. — The grinding of a hole that has keyways is more difficult than the grinding of a straight or plain hole. A keyway has a tendency to tear out the grains from the bond of the wheel, and, consequently, a much harder wheel is needed for this work. Fig. 16 shows two examples of internal grinding of holes having keyways. There are several points to observe in the grinding of key-seated holes. In the first place, a much wider wheel should be used than that recommended for a plain hole, also, the wheel should be operated by hand rather than by power feed, and should be moved rapidly back and forth, in order to secure a concentric hole. The use of a wide-face wheel and a rapid traverse generally prevents the keyways in the work from making the wheel grind out of round, as would be the case with a narrower wheel operated by power feed.



A

Work: — Low countershaft gear, 0.15 per cent carbon open-hearth steel drop-forging; carbonized 0.030 inch deep and hardened.

Operation: — Grinding internal diameter with a Norton (vitrified) alundum wheel, grain 60, grade M; 1⅜ inch diameter, 1⅛ inch face; speed, 10,200 R.P.M. — 3670 feet surface speed; work speed, 400 R.P.M. — 151 feet surface speed; amount removed from diameter, 0.005 to 0.008 inch.

Remarks: — Wheel is fed back and forth by pumping action, and is trued up with a carbon block; number of truings varies from 10 to 50 pieces; production, 200 in nine hours; machine used, No. 70 Heald internal grinding machine.

B

Work: — Low speed and reverse sliding gear, 0.15 per cent carbon open-hearth steel drop-forging; carbonized 0.030 inch deep and hardened.

Operation: — Grinding splined hole with a Norton (vitrified) alundum wheel, grain 60, grade N; 1⅜ inch diameter, 1⅛ inch face; speed, 10,200 R.P.M. — 3670 feet surface speed; work speed, 400 R.P.M. — 131 feet surface speed; amount removed from diameter, 0.005 to 0.008 inch.

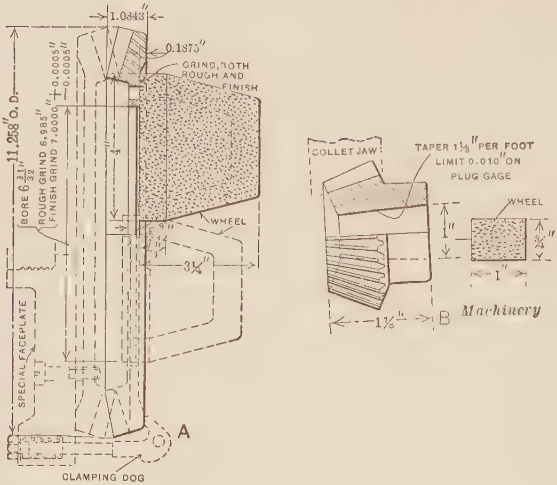
Remarks: — Wheel is fed back and forth by pumping action and is trued up with a carbon block, every 10 or 50 pieces; wheel is harder because of the greater number of splines; production, 200 in nine hours; machine used, No. 70 Heald internal grinding machine.

Fig. 16. Keyseated Holes Finished by Internal Grinding

The example shown at *B* has four keyways instead of one, and, in this case, a grade N instead of a grade M wheel is used. This wheel is slightly harder than that used for the example shown at *A*, as it has been found that the greater the number of keyways in the work, the harder the bond of the wheel should be. The grade N wheel requires dressing more frequently than the grade M wheel but gives better results, because, in a softer wheel, the grains tear out too easily from the bond and do not give the desired finish or give as large a production.

Considerable difficulty was at first experienced in grinding the holes in these gears and a large number of experiments were made with different grains and grades of grinding wheels. It has been found that wheels for internal grinding of small size do not come of as even a grade as large wheels used for external cylindrical grinding. Various means have been adopted to remedy this, and one method is to treat the wheels before using them. Where the work to be ground is hardened, and has keyways, making the use of a hard-bond wheel necessary, it has been found that the wheel will give much better results by being soaked in regular machine oil before using. The practice followed in one shop is to leave the wheel soaking in this oil for about twenty-four hours, and also, when not in use in the machine, to leave the wheel in the oil. The operator generally keeps a number of these wheels beside the machine in a can of oil, and uses one wheel for several hours, then takes it off the spindle, places it in the oil, and replaces it with a fresh one. The wheel is taken out of the oil, placed on the spindle, and cleaned off by means of an air blast, then dressed up with a carborundum block. The oil-treatment seems to make the wheel act as though it were softer and prevents it from glazing to a large extent.

The universal drive-shaft yoke, shown at *B* in Fig. 12, is a still more difficult proposition to grind than keyseated gears. In this case, over half the hole is completely cut away, leaving the work open on both sides. A hard-bond wheel does not work very satisfactorily, because it glazes rapidly and has a tendency to throw the grinding wheel-spindle out of line. The chief trouble met with in grinding this part was in getting the hole round; this was due to the tendency of the wheel to spring away when it struck the open portion of the work. The difficulty was finally overcome by adjusting the wheel and work-spindles so that they were rigidly supported, and also supporting the work in a special fixture, and clamping it from the end. It will be noticed, in this case, that the bond of the wheel was



Machinery

A

Work: — Bevel ring drive gear, 0.15 per cent carbon open-hearth steel drop-forging, carbonized 0.030 inch deep and hardened in oil.

Operation: — Grinding back face and internal diameter with a Norton (vitrified) alundum special-shaped wheel, 4 inches diameter, ¾ inch straight face, 3¼ inches wide; speed, 5400 R.P.M. — 5670 feet surface speed; work speed, 260 R.P.M. — 510 feet average surface speed; amount removed from diameter and back face, 0.010 inch when soft and hard.

Remarks: — In both cases hand feed is used, and owing to a peculiar fancy of the operator, the same grit and grain of wheel is used for grinding work when soft and hard; production when grinding soft is 200 in nine hours; when hard, 125 in nine hours; machine used, Heald No. 75 internal grinding machine.

B

Work: — Automobile rear axle drive pinion, 0.20 to 0.25 per cent carbon, 0.17 per cent vanadium steel drop-forging, heat-treated.

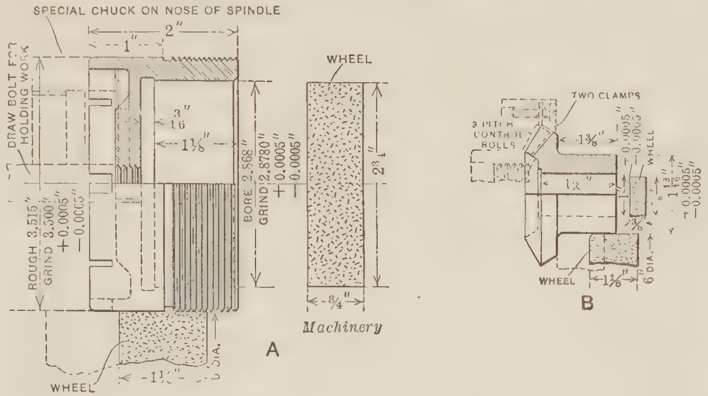
Operation: — Grinding taper hole with a Norton (vitrified) alundum wheel; grain 60, grade K; ¾ inch diameter, 1 inch face; speed, 12,500 R.P.M. — 2460 feet surface speed; work speed, 400 R.P.M. — 100 feet average surface speed; amount removed from diameter, 0.005 inch.

Remarks: — Wheel is fed in and out by pilot wheel; wheel is just trued down to start and then is not touched until worn down to about size of spindle; 200 pieces secured from each wheel; production, 700 pieces in eight hours; machine used, Bryant single-spindle chucking grinder.

Fig. 17. Examples of Internal, Face, and Taper Hole Grinding

considerably softer than that used for the examples shown in Fig. 16, but the conditions are not quite the same, and a hard-grade wheel was not satisfactory. The amount of metal to remove from the diameter was reduced to a minimum.

Combined Internal and Face Grinding Operations. — The bevel ring drive gear shown at *A* in Fig. 17 is a good example of combined hole and face grinding. The operations to be performed are the grinding of the hole and the back face. In order



A

Work: — Sleeve for transmission countershaft bearing, 0.15 per cent carbon open-hearth steel drop-forging, carbonized 0.030 inch deep and hardened.

Operation: — Grinding internal and external diameters; external diameter ground with a Detroit wheel, grain 46, grade M; 6 inches diameter, 1⅛ inch face; speed, 2160 R.P.M. — 3391 feet surface speed; work speed, 240 R.P.M. — 220 feet surface speed; amount removed from diameter, 0.015 inch. Internal diameter ground with a Norton (vitrified) alundum wheel, grain 50, grade K, 2¾ inches diameter, ¾ inch face; speed, 5600 R.P.M. — 4000 feet surface speed; work speed, 240 R.P.M. — 180 feet surface speed; amount removed from diameter, 0.010 inch.

Remarks: — Wheel is traversed by power for grinding both internal and external diameters; for grinding external diameter, traverse is at the rate of 64 linear inches per minute, and for internal diameter, at the rate of 66.5 linear inches per minute; production, 100 pieces in nine hours; machine used, Bryant two-spindle chucking grinder.

B

Work: — Bevel pinion, 0.15 per cent carbon open-hearth steel drop-forging, carbonized 0.030 inch deep and hardened.

Operation: — Grinding internal and external diameters and facing shoulder; external diameter ground with a Norton (vitrified) alundum wheel, grain 36, grade M; 6 inches diameter, 1⅛ inch face; speed, 2500 R.P.M. — 3927 feet surface speed; work speed, 240 R.P.M. — 114 feet surface speed; amount removed from diameter, 0.015 inch. Internal diameter ground with a Norton (vitrified) alundum wheel, grain 50, grade K, ⅞-inch diameter, ⅜ inch face; speed, 15,279 R.P.M. — 3500 feet surface speed; work speed, 240 R.P.M. — 63 feet surface speed; amount removed from diameter, 0.015 inch.

Remarks: — Wheel is traversed by power for grinding both internal and external diameters, at the rate of 64 linear inches per minute; shoulder is faced by bringing wheel up slowly before grinding external diameter; production, 15 pieces per hour; machine used, Bryant two-spindle chucking grinder.

Fig. 18. Two Examples of Combined Internal and External Grinding

to cut the teeth, these surfaces are used for locating, so that the work is ground both before being hardened and after hardening. One method of holding a gear of this kind for grinding is shown in the illustration. A duplicate ring gear is fastened to the faceplate to locate the gear to be ground from the teeth, two clamping dogs holding the gear in place. In the first grinding operation, the back face is just trued up and about 0.010

inch is removed from the hole. The production, when the gear is soft, is 200 gears in nine hours.

After the teeth are cut in the gear, it is carbonized and hardened. It is then held on the same type of fixture, as before, for another grinding operation; the same grade and grain of wheel is used. The back face and hole are both ground by feeding the wheel by hand. Generally, the same grade and grain of wheel is not recommended for hard and soft work, as a soft wheel gives better results on hard than on soft work. In this case, the operator previously used a softer wheel on the hardened work but found that the gain was not sufficient to warrant the changing of wheels. Another point is that the amount of surface being ground is so small that the grain and grade of wheel does not make very much difference. In fact, a rather wide range of wheels could be used. The production after hardening was considerably less than when the gear was soft and averaged about 125 gears in nine hours.

Combined Internal and External Grinding. — Fig. 18 shows two examples of combined internal and external grinding performed on a Bryant two-spindle chucking grinder. The example shown at *A* is a sleeve for a transmission countershaft bearing, the internal and external diameters of which are ground at the same setting by bringing the external and internal grinding wheels alternately into position. The other example, shown at *B*, is a bevel pinion that is handled in a similar manner. In addition to grinding the external diameter of the pinion, the back face is also ground by bringing the wheel up slowly against the face of the work when taking the roughing cut from the external diameter.

As the foregoing examples of internal grinding indicate, there is a considerable difference in the wheel and work speeds used, and an endeavor, in each case, has been made to explain why such variance in practice existed. It is impossible, of course, to lay down fixed rules for internal grinding, but these examples and the accompanying data illustrate general practice.

CHAPTER IV

CYLINDER GRINDING

THERE are two general methods of machining the cylinders of gas and gasoline engines: First, by boring and reaming, and second, by boring and grinding. In the manufacture of motors for automobiles, the grinding method is employed quite extensively at the present time, but the cylinders for many gasoline engines, of the type used on farms and for industrial purposes generally, are finished by boring or by boring and reaming. When there is an opening at the compression end of the cylinder, which makes it possible to support a boring-bar or reamer at both ends, naturally, reamers can be used to better advantage than when one end of the cylinder is closed. With closed end cylinders, the boring machine must be extremely rigid or else the boring-bar, and also the reamers used, will tend to follow the cored hole, with the result that the finished hole is not square with the crank end of the cylinder.

In the manufacture of large and heavy gas engines, where the cylinder walls are relatively thick, the boring and reaming method is commonly employed, but for smaller cylinders, especially when the walls are comparatively thin, the use of a grinding machine for finishing becomes more imperative, if the greatest degree of accuracy is desired.

The design of the cylinder, however, is not the only factor that is considered by manufacturers. The service for which the motor is intended often has a bearing upon the method of finishing the cylinder bore. A great many cylinders for the cheaper class of gas and gasoline engines are finished, at the present time, by boring and reaming, whereas automobile motors and others which must withstand severe duty are often ground, in order to secure as true a cylindrical surface as possible. When small and medium-sized cylinders are finished by boring and reaming, either in some form of turret lathe or special machine designed for this purpose, they can be produced more cheaply than when finished by boring and grinding, so far as the machining cost is concerned. Whether there are disadvantages resulting from the reaming method which offset the lower machining cost may depend upon the design of the cylinder as well as upon the service for which it is intended.

The objections to the boring and reaming method, which are commonly cited, are as follows: In the first place, it is contended that the thin walls of the cylinder are liable to spring away from the cutter or reaming tool, if there happens to be a hard spot in the iron, thus forming a high surface which will cause the piston to leak and diminish the compression in the cylinder. If the cylinder is of the two-cycle type, another difficulty may be encountered when finishing by means of a cutter or reamer, owing to the ports in the walls of the cylinders. The errors which may result from the causes mentioned are subject to wide variations and may depend not only upon the design of the cylinder itself but upon the design and condition of the tools used for the work.

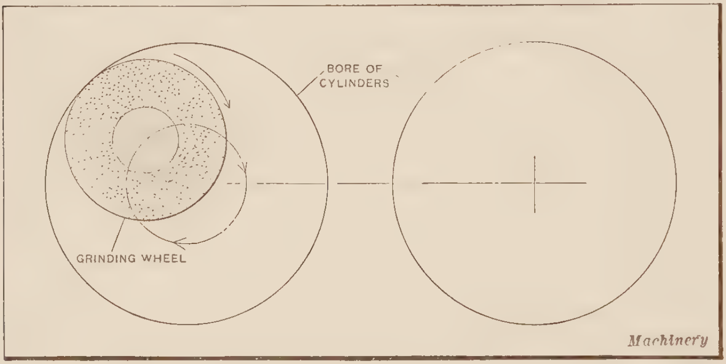


Fig. 1. Diagram illustrating Method of Grinding Cylinders on Machines of Eccentric-head Type

The chief advantages of grinding are that the accuracy is not affected by the springing of the cylinder walls, by hard or soft spots in the iron, or by side ports, in the case of the two-cycle cylinder, because a grinding wheel of the proper grade cuts the metal with very little pressure. Moreover, the operation of lapping, which is used in some shops to secure a better fit between the piston and cylinder, is unnecessary when the bore is accurately finished by grinding. It is assumed, of course, that the piston rings are properly made; the outer surface or periphery should form a true circle when the ring is inserted in the cylinder and it is advisable to finish this outer surface by grinding.

For grinding cylinders, a special type of internal grinding machine has been developed in which the work does not have to be rotated, as is the case with the ordinary type of internal grinding machines. The grinding wheel not only rotates about its own axis but has a circular or planetary movement (as indicated by the diagram, Fig. 1) so that it follows around the walls of the hole being ground as the work is fed in a lengthwise direction. A table mounted on a traveling carriage is provided for supporting the work. The grinding spindle is carried in double eccentrics, *i.e.*, one eccentric inside another, which are mounted on the headstock of the machine. The two eccentrics may be rotated relatively to each other, to increase or decrease the eccentricity of the wheel-spindle, and thus give the wheel a circular path of varying diameter. The cylinder to be ground is traversed with relation to the grinding wheel, and after the wheel reaches the bottom of the hole, the automatic feed is reversed and the cylinder fed out. As the work travel reverses, the wheel is fed outward for taking another cut, as it is traversed through the cylinder bore. Before considering some of the more important points connected with cylinder grinding, two machines especially adapted for this work will be described in a general way.

Heald Cylinder Grinding Machine. — The cylinder grinding machine shown in Fig. 2 is adapted not only to the grinding of gas and gasoline engine cylinders but to a variety of other internal grinding operations. A machine of this type is of especial value when the parts to be ground are of such a shape that it is impracticable to revolve them. As explained in the foregoing, it is equipped with a grinding spindle, which, in addition to rotating about its own axis, has an eccentric rotating movement.

On the front of the column, a knee *A* is mounted, which carries the main sliding table *B* and provides vertical adjustment. The main table has a cross-slide table *C*, so that two, three, or four holes in the same cylinder casting can be ground to accurate center-to-center distances by simply adjusting the table laterally.

The travel of the main table is automatically reversed at any desired point which is controlled by the position of the dogs shown. The rate of the travel is varied by a quick-change gear-box seen on the front of the column. The head carrying the wheel-spindle is driven through a quick-change speed-box located at the base of the machine. The machine is equipped with a centrifugal pump and a large water tank, for use in maintaining a uniform temperature of the work during grinding, the water being pumped into the jacket and over the outside of the cylinder and not inside of the bore. The advantage of grinding in this way will be referred to later. This machine also has an exhaust fan for carrying away the dust produced in grinding.

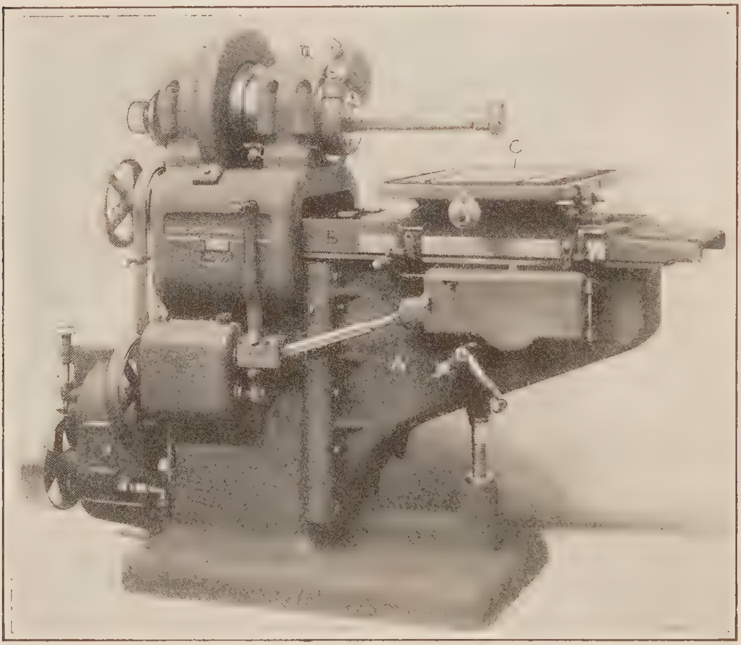


Fig. 2. Heald Cylinder Grinding Machine

The grinding head, a detailed view of which is shown in Fig. 3, consists of two eccentrics, as previously mentioned; one located within the other, and the outer or larger eccentric revolves in the main bearings of the machine. The hole in the large eccentric, in which the inner eccentric is fitted, is not centrally located, and, moreover, the hole in the inner eccentric, through which the spindle passes, is also in an eccentric position; therefore, by revolving the inner eccentric within the outer one, the amount of eccentricity of the wheel-spindle, in relation to the axis of rotation, may either be increased or decreased, thereby causing the wheel-spindle and grinding wheel to rotate about a circle of larger or smaller diameter. This adjustment provides means for grinding holes of different size and also for feeding the wheel in or out. It is effected by means of a geared feed mechanism illustrated in Fig. 3.

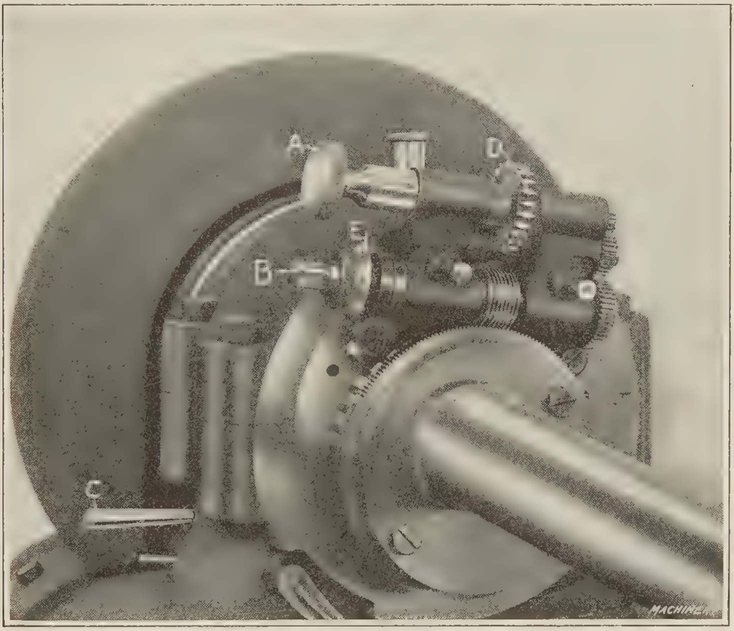


Fig. 3. Mechanism on Heald Machine for Varying Eccentricity of Grinding-wheel Spindle

When a small adjustment is desired, such as would be required for varying the depth of the cut, this may be made by turning the knob *A*, whereas, for large adjustments, such as might be necessary for grinding holes of different size, a crank would be applied to shaft *B*. The micrometer dial *E* makes it possible to adjust the wheel a definite amount with great accuracy. While the knurled knob *A* is most generally used for fine adjustments, when the head is in motion and revolving at one of the lower speeds, it is preferable to use the lever *C* at the left of the main bearing, when the head is rotating at the higher speeds, as when taking a finishing cut. When this lever is drawn toward the bearing by the operator, it serves to turn the star-wheel *D* one notch for every rotation of the head, which represents an adjustment of about 0.00025 inch in radius.

The cross-slide table is equipped with adjustable dogs which can be set to give approximately the center distance when transferring from one hole to another. The exact center may be obtained by means of the micrometer dial on the cross-feed screw, which should be set at zero for the first hole, and the position of the dial noted for the other holes.

Brown & Sharpe Cylinder Grinding Machine. — Another design of cylinder grinder is illustrated in Fig. 4. This machine is also equipped with a grinding spindle which has a planetary motion. The work to be ground is mounted either upon the sliding table *A* or cross-table *B* and is ordinarily held in a suitable fixture. For ordinary cylinder grinding, the fixture, as a rule, may be of simple design. The cross-table rests upon a saddle, which, in turn, is mounted upon the sliding table and is clamped by bolts which slide in a T-slot, so that the saddle can be moved along table *A* to any desired position. Four adjustable stops are provided on the edge of the cross-table; these stops engage a block on the saddle to aid in properly locating the cross-table laterally. This block is hinged and may be swung down and out of the way of the stops.

The wheel-spindle is driven by a belt which passes under two idler pulleys *D* and *E* and over pulley *F* on the spindle. One idler pulley is stationary and the other is mounted upon an adjustable arm, the tension of the belt being regulated by a spring, which may be seen at the right-hand end of the machine.

The spindle-revolving drum carries the spindle and rotates it within any radius up to the maximum capacity of the machine. The drum is driven from overhead works through cones that provide different speeds. A fast and slow series of speeds is obtainable by means of a lever attached to the front of the machine. The front end of the spindle is tapered to receive the wheel sleeves. The wheel-spindle has both rapid and fine adjustments for grinding different diameters, the former being obtained by a crank which is inserted into the head, and the latter by a lever *H* at the front of the spindle head. The wheel may be fed to the work or withdrawn from it without stopping the mechanism.

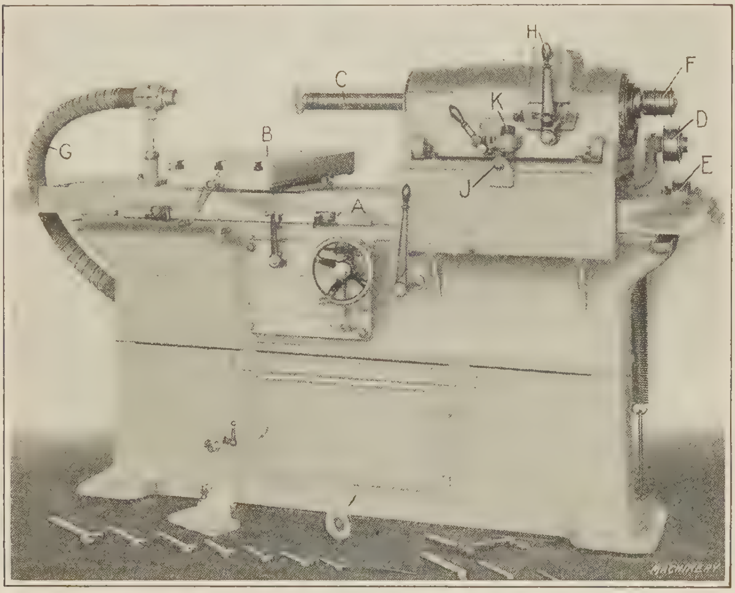


Fig. 4. Brown & Sharpe Cylinder Grinding Machine

The wheel-spindle head is mounted upon a bridge which spans the work-table, as the illustration shows. This head is provided with means for slight vertical and transverse adjustments which are used for aligning the spindle with reference to the fixture in which the cylinder is held when the fixture is first placed on the machine. The spindle head is also adjusted, in some cases, when the cylinders to be ground have been bored a little higher or lower than they should have been. These spindle-head adjustments, however, are of the greatest advantage when regrinding cylinders, if the latter are not located by a fixture and the spindle must be set for each job. The transverse adjustment is made at *J* and the vertical adjustment at *K*.

An exhaust fan, driven from the overhead works, is attached to the rear of the machine and serves to draw the dust away from the work and into a tank partly filled with water. The fan is connected with the part being ground by the flexible rubber tubing *G* seen to the left of the machine. A wet grinding attachment may be applied to this machine, although it is not a part of the regular equipment. The subject of wet and dry cylinder grinding will be considered later.

Having now considered some of the more important features of these special cylinder grinding machines, a number of points that should be considered in connection with this work will be referred to. Much of the following information on cylinder grinding was obtained from the Heald Machine Co.

Selecting Wheels for Cylinder Grinding. — The importance of selecting a wheel of the correct grade and grain, for the particular quality of iron to be ground, cannot be over-estimated, as the wheel used very materially affects the production and quality of the work. If the wheel glazes and cuts slowly, it is too hard, resulting in a very small production and holes that are not straight or round. The best plan is to use just as soft a wheel as will stand up under reasonably heavy cuts; more work of better quality will be the result. In selecting wheels, it is very important to consider the different grades of iron that may be used from time to time. Frequently, a change of wheel will result in a considerable reduction in the time required for grinding, and, sometimes, it will enable one to obtain a round hole when there have been difficulties in this particular.

Many suppose, that, in order to produce a smooth surface, a fine wheel is necessary; this is not the case, however, as the quality of the surface depends more upon a true wheel-face and the feeds and speeds used in grinding, than upon the grain of the wheel. It will generally be found true that a moderately coarse and free-cutting wheel is the most satisfactory. Ordinarily, if the operator errs in any respect, it will be in using too fine or too hard a wheel. Do not think because a wheel wears down quickly that a harder one would be more economical; as a general rule, increasing the hardness of the wheel causes such a reduction in output that the cost of the wheels will be a mere trifle in comparison. There should be no difficulty, where other conditions are right, in producing a good surface with a fairly coarse wheel, say, from 46 to 60 grit or grain, and a grade not harder than *K* (Norton system of grading), but the wheel must be trued up so that it runs perfectly true on its face.

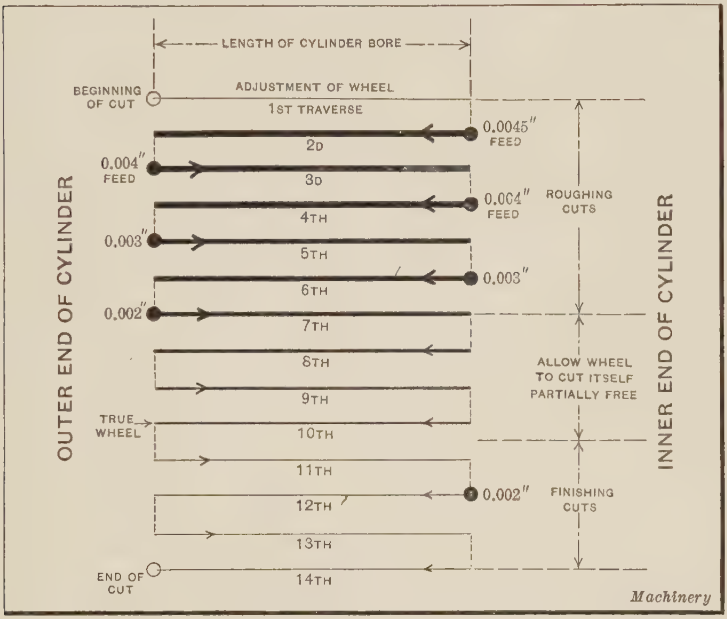
Wheels made from carbide of silicon abrasives, such as carborundum and crystolon wheels, are recommended for cylinder grinding. While the exact determination of the correct grain and grade is a matter of experiment, one of the following seven crystolon wheels should prove satisfactory: 30-I, 30-J, 30-K, 36-I, 36-J, 36-K, 50-H. As coarse and soft a wheel should be used as possible, as it cuts faster and freer, and tends to produce a straighter and rounder hole than wheels of harder grade and finer grain. The soft wheel also requires the expenditure of less power. As with other grinding operations, a hard dense iron requires a softer wheel than would softer iron. Other conditions being equal, a softer wheel should also be used when a comparatively large amount of material is to be removed by grinding. When the cylinder walls are quite thin and easily distorted in boring, a slightly softer wheel should also be used, in order to take care of the uneven distribution of the metal. When cooling water is circulated through the jackets, slightly harder wheels may sometimes be used. A harder bond is also desirable when there are ports in the cylindrical wall, because these ports have a dressing or shaving action upon the surface of the wheel.

Gas engine manufacturers have different ideas as to the quality of finish for cylinders; consequently, one manufacturer will use a coarse, rapid-cutting wheel and obtain a medium grade of finish, whereas, another will prefer a finer, slower-cutting wheel, in order to obtain a smoother finish. Some wheels for this work are of grains of a single size, whereas others are a mixture or combination of different sizes. The American Emery Wheel Works recommend carbolite wheels having a grain varying from 30 to 60. The grades in which these wheels are supplied for cylinder grinding are usually H, I, J, K, and L, the softer wheel grades being used for the harder grades of cast iron, and *vice versa.*

In selecting the grade of the wheel, the rigidity of the grinding machine is a point which is often disregarded, although it is an important factor. Other conditions being equal, a softer wheel may be used in a stiff, rigid machine than in one which vibrates considerably during the grinding operation. For instance, a wheel of grade J might be suitable for a rigid machine but entirely too soft on another machine loosely adjusted or not so rigidly built. When the grinding spindle vibrates, the abrasive grains are torn from the wheel, not only by the grinding action, but as the result of the vibration, so that a wheel of harder grade is necessary.

Method of Operating Cylinder Grinder. — When grinding cylinders for automobiles and marine motors, the output depends upon the method of operating the machine as well as upon the machine itself and the proper selection of feeds, speeds, and a suitable grinding wheel. The following general information on the method of handling a cylinder grinding machine of the type illustrated in Figs. 2 and 3 was obtained from *Grits and Grinds* published by the Norton Co. It is assumed that the cylinders are cast *en bloc* or in one solid piece, and that the bore is from 0.005 to 0.020 inch undersize, this being the amount left for grinding.

The cylinder casting is clamped in a fixture bolted to the table of the machine and the dust exhaust nozzle should be connected to the rear end or top of the cylinder. It is also preferable to circulate cooling water through the water jacket of the cylinder. The operator first adjusts the eccentric grinding-wheel spindle until the wheel is cutting evenly all around the hole; this being done on the first or in-traverse of the table. The wheel is then fed in heavily (about 0.004 or 0.005 inch) just before the outward traversing movement begins; the wheel being allowed to cut under this pressure for about two traverses or strokes. Then, if the total amount of material to be removed warrants it, the wheel is again fed in a similar amount, or enough to reduce the size of the cylinder to within about 0.002 inch of the required diameter. Usually, an examination of the interior surface, at this stage, indicates that the wheel-face should be trued with a diamond, in order to secure the desired finish.



Machinery

Fig. 5. Chart showing Traversing and Feeding Movements of Wheel when Grinding a Cylinder

If no cooling water is circulated through the water jacket, the heat generated by grinding will undoubtedly expand the cylinder wall an appreciable amount, and the operator must use his judgment as to how much the hole should be ground oversize to compensate for the skrinkage when the casting cools. The size of the bore is usually determined by using a plug gage or an inside micrometer caliper. The diagram shown in Fig. 5 illustrates graphically about how the feeding of the wheel is varied for the different stages of the grinding operation and also the number of traversing movements necessary under ordinary conditions. The grinding operation represented by this particular diagram, however, was not particularly favorable to a good record. The cylinders were the single type with a $4\frac{3}{4}$-inch bore, $9\frac{1}{4}$ inches long. The material was hard dense iron and no cooling water was used in the jackets. The time for grinding, including handling and wheel truing, was seventeen minutes per cylinder. As the diagram indicates, the wheel, while taking the roughing cuts, was cutting under rather severe pressure due to the frequent feeding in of the wheel without allowing it to cut itself free. This procedure was followed in order to secure the desired rate of production.

The principal factors which effect the grinding action and the kind of wheel required may be summed up under the following heads: Hardness and texture of the iron; amount of material to be removed by grinding; thickness of cylinder wall; shape of casting and general distribution of metal; whether, or not, water is circulated around the cylinder walls; whether, or not, the cylinder has ports; the combination of the wheel speed, eccentric rotation of the wheel, and the table traverse; the presence of oil or dirt on the cylinder wall; and the intelligence and skill of the operator.

Spindle Rotation and Work Feed. — No fixed rule can be given for determining the proper combination of eccentric or wheelhead rotation and table traverse for cylinder grinding, since the speed and feed depend upon the kind of wheel being used, the amount of metal to be removed, and the hardness of the iron. Frequently, a slight change in the hardness or texture of the iron will necessitate either a change in the speed or feed or the use of a grinding wheel of different grain and grade, and, in some cases, both changes are desirable. If there is little stock to be removed from the cylinder bore, it doubtless would be advisable to regulate the table traverse, so that a feeding movement equal to about three-quarters of the wheel width is obtained; in conjunction with this rapid traverse, comparatively light cuts would be taken. On the other hand, if there was considerable stock to remove or in case the material was hard to grind, it might be preferable to reduce the feeding movement and take deeper cuts, so that the leading corner of the wheel would do most of the cutting; with this method, the cylinder wall would probably be subjected to less pressure than when nearly the full width of the wheel-face was doing the grinding.

Both coarse and fine feeds are used for finishing, the method often depending upon the personal preference of the operator or manufacturer. Those who desire a very smooth finish use fine feeds, so that there is no trace of feed marks in the finished bore. In other shops, where slight feed marks are not considered objectionable, a coarser feed or more rapid table travel is employed and good results are obtained by this method, provided the wheel-face is properly trued for finishing. In fact, after the cylinder has been used a short time, the bore will be rubbed down, so that there is no perceptible difference between the surface produced with a fine feed and the one ground by using a coarser feed.

If it were possible, in every case, to secure the ideal wheel as to grade and grain, and castings were exactly uniform as to hardness, etc., then on a given machine, standardized conditions could be established; but, in a factory having several machines which may differ slightly as to adjustment, etc., and with castings and grinding wheels varying slightly, it is impossible to standardize the traverse of the table per revolution of the wheel, speed of rotation, or the depth of the cut, and the most efficient results depend, in part, upon the experience and intelligence of the operator.

It is common practice, when taking the roughing cut, to rotate the head slowly and use a feed for the work-table equal to about one-half or three-quarters of the wheel width. After the stock has been removed to within about 0.00025 inch of the required size, the wheel should be trued carefully for the finishing cuts, and then the speed of rotation for the eccentric head should be increased and very light cuts taken until the hole is ground to size. When finishing, the wheel should be allowed to run through the work at least two or three times without any increase of cut, so that any possible spring in the spindle will be eliminated. Ordinarily, for finishing, the feed or table traverse is reduced, in order to remove the feed marks. although, by using the most rapid table feed for the final cuts, the time for the finishing operation may be reduced and the surface produced will be smooth enough for practical purposes.

A wheel with a $\frac{3}{4}$-inch face is now being used in many shops instead of the $\frac{1}{2}$-inch wheel which has been used so extensively. This wider wheel is said to increase the production and it also permits the use of a slightly softer grade. When roughing, inasmuch as the advancing edge of the wheel does most of the work, it is apparent that the alternate use of first one-half the wheel-face and then the other half, by reversing the position of the wheel on the spindle, tends to cause the wheel to wear evenly. If there is surface dirt or oil in the cylinder, this should be removed before attempting to grind, as, otherwise, a soft free-cutting wheel is liable to cut and glaze.

Allowance for Cylinder Grinding. — The allowance for cylinder grinding should ordinarily be about 0.010 inch. Obviously, this allowance may be either too small or too large. In many cases, too much material is left for grinding, either because it is feared that the cylinders will not "clean up" or be entirely true, owing to inaccurate boring, or because of carelessness in allowing the boring tools to be under size. This allowance might be as small as 0.004 or 0.005 inch, or as high as 0.050 inch, but the latter amount is excessive and it is preferable to reduce the hole by boring to within, say, 0.008 or 0.010 inch of the desired size; the output might be increased by allowing even less, although, for average conditions, this is not recommended. Since the time for grinding depends partly upon the allowance, the importance of rough-boring the cylinders can be readily appreciated. It is not necessary that the boring be done so as to leave a smooth finish, but the hole should be reasonably true, approximately cylindrical, and square with the flange on the end of the cylinder. It is much more economical to prevent errors in machining, that may easily be avoided, than to correct these errors on the grinding machine.

Truing Wheel for Cylinder Grinding. — When truing the wheel of a cylinder grinder, the head, of course, should remain stationary, the spindle being allowed to rotate in one position. A diamond should be fed across the wheel-face by traversing the work-table. This diamond should be rigidly held to the work-table or to the fixture. It is the practice of the Heald Machine Co. to mount the truing diamonds in special brackets which are usually bolted to the face of the work-holding fixture, as shown in Fig. 6. The wheelhead is turned until the wheel is directly in front of a diamond, which is then adjusted toward it sufficiently to make the proper contact. When rough-grinding, it does not matter if the wheel surface becomes coarse and somewhat rough, as it then tends to cut freer; before taking the finishing cuts, however, the wheel should be trued. When grinding small holes, the wheel does not need to be trued as frequently as for larger work. A wheel dresser or a brick of abrasive held in the hand should not be used for wheel truing. Sometimes wheels are not of an even thickness which makes them out of balance when running at the high speeds required. In such cases, the operator should true up the wheels on the side as well as the face, to correct this error, because a wheel that is out of balance sets the spindle vibrating and makes it difficult or impossible to obtain a good surface on the work.

Annealing Cylinders. — Some manufacturers anneal their cylinders after the rough-boring operation, in order to facilitate whatever permanent changes of shape are likely to occur, due to the removal of the stock by boring. This annealing of the cylinders, and finishing them to accurate size afterwards, is to be recommended.

Temperature of Cylinder for Grinding. — When a cylinder is being ground, it is advisable to maintain a uniform temperature in the cylinder casting, to prevent distortion. For instance, if the heat generated by the grinding operation were to distort the cylinder walls, obviously, the bore would not be cylindrical when it became cool. In order to maintain a more uniform temperature, when grinding, water is circulated through the jacket and over the outside of the cylinder near the crank end. The water is not used in the bore of the cylinder, the grinding being done dry rather than wet. According to the Heald Machine Co., most manufacturers who finish cylinders by grinding use cold water for maintaining a uniform temperature. There are those, however, who believe in grinding cylinders hot, by using hot water instead of cold. The reason given for this practice is that, inasmuch as the cylinders are hot when the engine is running, the grinding should be done under conditions somewhat similar to those which exist in actual service. In other words, if the cylinder is ground true while hot, it will naturally assume this true form when heated.

Ordinarily, it would be more convenient to supply cold water than hot, and some manufacturers contend that cold water is also preferable, because the inspection of a cylinder for accuracy that has been ground cold is an easy matter, whereas one that has been heated by grinding becomes cold before the inspector receives it, and, consequently, he cannot determine within what limits of tolerance it was ground by the operator. As to the grinding of cylinders while hot, experience has shown that there is considerable variation in the amount that different castings will change in shape, due to a rise in temperature. This variation is caused by the difference in the design of cylinders or the relative locations of port openings, walls, etc. For this reason, a careful examination of the change caused by temperature variations should be made before deciding whether to grind hot or cold; thus, if the cylinder casting changes but slightly, the advantage which might be gained by grinding hot will doubtless be more than offset by the inconvenience of the hot-water method.

Wet and Dry Cylinder Grinding. — The question of wet and dry grinding has been thoroughly tested and the general experience has been entirely in favor of dry grinding, that is, without water on the wheel or in the hole. According to tests of the Heald Machine Co., wet grinding does not give a satisfactory surface to the work or allow the removing of satisfactory amounts of stock by the different cuts; moreover, there seems to be a tendency for the wheel to load up with dirt, which difficulty is not experienced in dry grinding. As the purpose of using water is to maintain the work at a uniform temperature, it is recommended that water be run into the jacket, and over the outside of the cylinder, as previously mentioned, thus securing all the advantages of dry grinding and also the advantages of uniform temperature.

Causes of Inaccurate Work. — If, at any time, there is trouble in obtaining round holes, first make sure it is not due to the cooling off and unequal contraction of the work between the time of grinding and measuring of the hole, for, if the cylinder is ground without the use of water, it will expand to quite an extent, and, in cooling, will contract unevenly according to the distribution of the metal in the cylinder. If this is not the cause and the error is in the grinding, then wheels of other grades and grains should be tried. Very frequently, this will correct the difficulty; if it does not, then the machine must require adjustment at some important point. The grinding-wheel spindle may be too loose in its bearings. The inner eccentric may be loose in the main rotating head, either at one or both

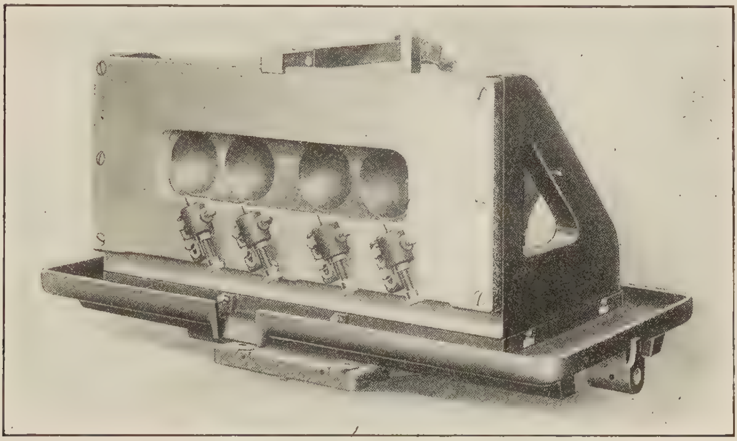


Fig. 6. Front View of a Fixture used on Heald Cylinder Grinding Machine

ends, or the gib screws in the table may require adjustment. A very slight adjustment of some of these parts will often make a great improvement in the accuracy of the work.

Fixture for Cylinder Grinding. — The fixture which is used for holding the cylinder while the bore is being ground is a very important part of the equipment. This fixture should be so constructed that the bored cylinder can be quickly located with reference to the spindle of the grinding machine. Figs. 6 and 7 show front and rear views of a fixture designed by the Heald Machine Co. for holding a four-bore casting. This same design would, of course, be equally satisfactory for either single or duplex cylinder castings. The finished face of a casting is clamped against the faceplate of the fixture by a single bar-shaped clamp which extends across the end of the casting, as shown in Fig. 7. In order to release the work, the eccentric clamping lever is pushed upwards and the bar swung down out of the way.

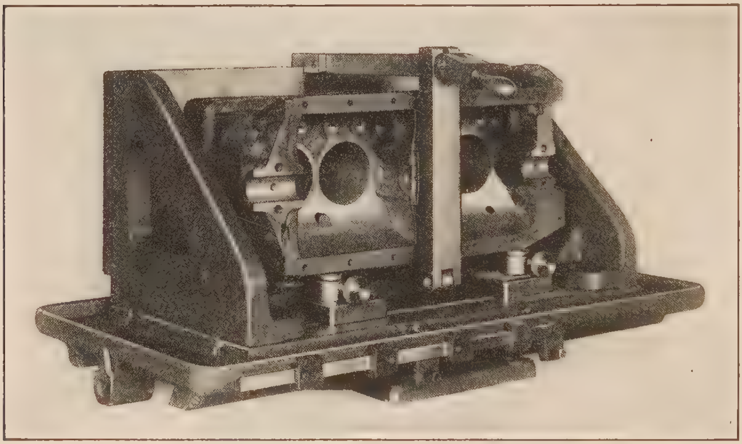


Fig. 7. Rear View of Cylinder Grinding Fixture

To locate the four-bore cylinder vertically and horizontally in this fixture, two plugs are used, one being placed in each end hole. These plugs rest upon the lower edge of the rectangular opening in the faceplate and the casting is shifted until the plug at the left-hand end of the cylinder bears against the end of the faceplate opening. In this way, the work is accurately located, and, after it is clamped in position, the plugs are removed. This same method of locating may be used for either duplex or single cylinders, with the exception of those having a "neck" finished on the flange end; with this form of cylinder, the neck is utilized in the same way as the plug.

Re-grinding Worn Cylinders.—Cylinder grinding machines are often used in repair shops throughout the country for re-grinding worn cylinders. They are unsurpassed for this work because a minimum amount of stock has to be removed to true up the hole, and, if the walls should happen to be scored deeply on one side (which is often caused by a loose wrist-pin), the machine can be set to grind mostly on that side, thereby removing the least possible amount of stock to true up the bore. The leading manufacturers now carry oversize pistons and rings in stock; therefore, the repair man has simply to grind out from 0.010 to 0.030 inch, as may be necessary, and then insert the proper size pistons and rings, and the cylinders are as good as when new.

CHAPTER V

SURFACE GRINDING

THE grinding of plane or flat surfaces is known as surface grinding and differs from cylindrical grinding in many respects. In the first place, the wheel makes greater contact with the work, especially when cylinder or cup wheels are used; consequently, more trouble is experienced with heating and warping. The surface grinder is indispensable in the tool-room for truing parts that have been distorted by hardening and for producing fine accurate surfaces. Many of the machines built, at the present time, are also efficient for producing flat surfaces in connection with manufacturing operations. Ordinarily, the surface grinder is used for finishing parts which have been milled or planed approximately to size, although many pieces are ground from the rough on the large machines used for manufacturing purposes. Surface grinding, in connection with tool-room work, is generally done dry and is used chiefly as a means for correcting hardened parts, or in cases where exceptional accuracy is desired. When surface grinding is done wet, little trouble is experienced in heating and warping, but it is not always feasible to use water or other cooling mediums, owing to the nature of the work and other requirements. Several interesting methods of preventing undue heat and warping in grinding dry, as well as different examples of work with complete data, will be given in the following.

Surface Grinding Methods. — Surface grinding is done on several different types of machines, some of which are adapted principally to tool-room work, and others, to general manufacturing. A common method of grinding a flat surface and one that is generally used on tool-room work is shown by the diagram *A* in Fig. 1. The work *a* is traversed beneath the grinding wheel *b*, as indicated by the dotted line, and either the wheel

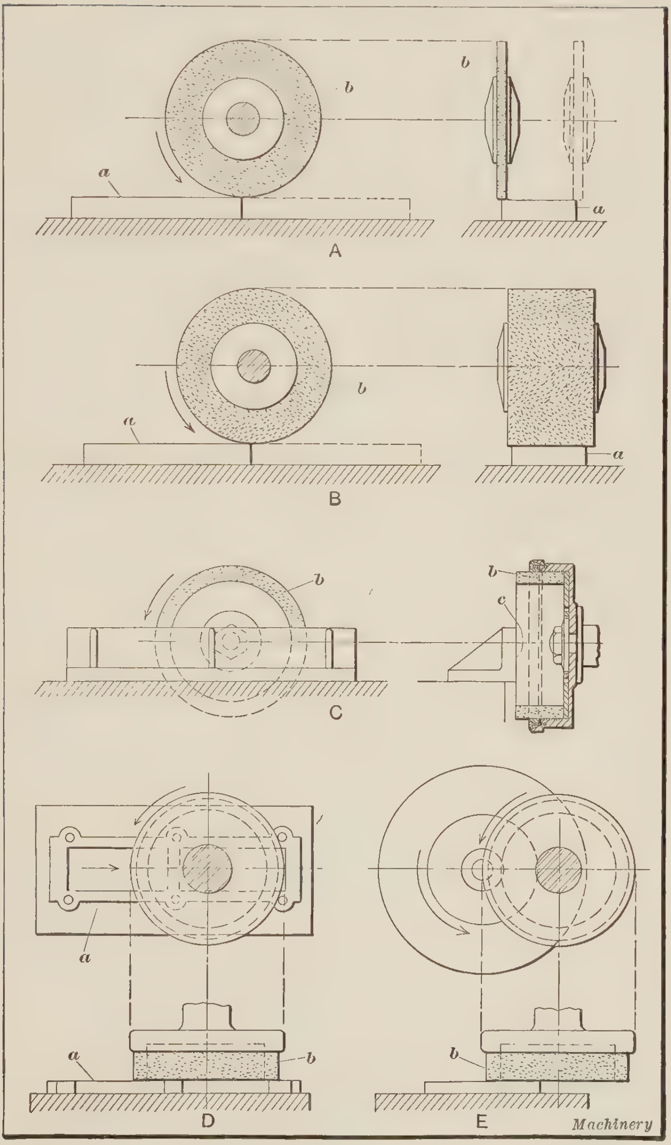


Fig. 1. Diagrams showing Different Methods of Grinding Plane Surfaces

or work is fed laterally (see end view) at each end of the stroke, so that the periphery of the wheel gradually grinds the entire surface. With this method of grinding, especially on thin work, considerable trouble is experienced with local heating and warping. In order to reduce this trouble to a minimum, light cuts with coarse traverse feeds — almost equal to the width of the face of the wheel per each stroke — are advisable. The chief cause of warping is due to the fact that the heat generated by grinding cannot be absorbed quickly enough by the part being ground to allow it to expand uniformly and the expansion of the heated surfaces causes it to assume a convex shape. When the wheel is removed and the heat has been absorbed by the work, the ground surface will be concave, and to grind it perfectly flat, light cuts with fast side feeds of the wheel are necessary, in order to cover the surface quickly and insure a more even distribution of heat.

Another method of producing flat surfaces is shown at *B* in Fig. 1. In this case, it will be noticed that the wheel *b* is slightly greater in width than the work and covers the entire surface to be ground. When using this type of wheel, the grinding must be done wet, as the surface contact of the wheel on the work is greatly increased. When the grinding is done wet, very accurate work can be secured by this method, provided the wheel is properly trued.

The diagram at *C* shows still another method of producing flat surfaces. The wheel *b*, in this case, is of the cylinder or ring type, and the vertical surface *c* is ground by being traversed past the face of the wheel; hence, this is often called face grinding. This method of grinding is used quite extensively in the grinding of comparatively large castings such as crankcase covers, gear housing, crankcases, and similar work.

The diagram shown at *D* illustrates the operation of what is known as the vertical surface grinder. The grinding is done either by a cup or cylinder wheel *b* which revolves about a vertical axis. The work *a* is held on a reciprocating table by means of a magnetic chuck or fixture and is traversed back and forth beneath the grinding wheel. The wheelhead remains stationary, as far as lateral motion is concerned, and is fed down gradually at the end of each stroke until the desired amount of material has been removed. Grinding on a machine working on this principle is always done wet.

The diagram shown at *E* illustrates the operation of another type of vertical surface grinding machine. In this case, the work-table has a rotary instead of a reciprocating movement, and the head carrying the cylinder wheel *b* is fed down a certain amount for each revolution of the work-table. This type of machine is suitable for grinding piston rings, facing the sides of ball bearing race rings, and for many other machine and engine parts. It can also be used for the grinding of the sides of saws, the required clearance being obtained by setting the axis of the wheel-spindle to an angle less than 90 degrees with the top surface of the work-table. There is another type of rotary surface grinder which differs from the type indicated at *E* in that a disk-shaped grinding wheel is used, the wheel being mounted on a horizontal spindle.

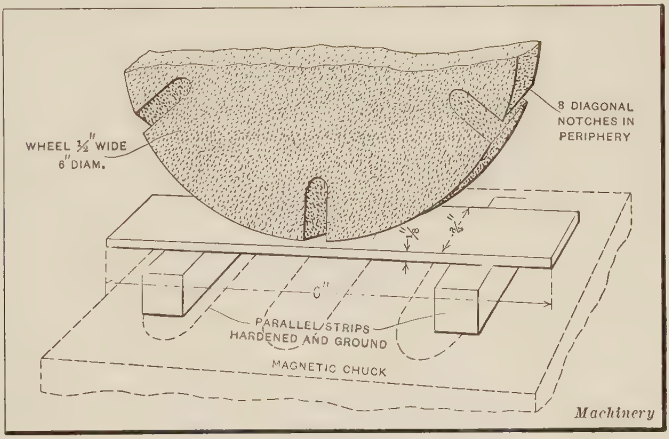

8 DIAGONAL NOTCHES IN PERIPHERY
WHEEL ½" WIDE 6" DIAM.
1/8"
3/8"
6"
PARALLEL STRIPS HARDENED AND GROUND
MAGNETIC CHUCK
Machinery

Fig. 2. Method of Preventing Thin Work from Warping when Grinding Dry

Cooling Water for Surface Grinding. — When it is possible to use water, the trouble generally experienced from heating and warping of the work can be overcome. For the grinding of cast iron and hardened steel, sufficient sal-soda should be added to the water, to prevent rusting. For grinding soft steel, it is advisable to add some cutting oil to the soda water, as this will improve the finish on the work. The amount of oil used in the soda water is generally in the proportion of 1 gallon of mineral lard oil to 32 or 35 gallons of soda water. On machines of the type illustrated by diagrams *D* and *E*, Fig. 1, plenty of cutting lubricant should be used inside the rim of the wheel, as overheating of the wheel-face is likely to cause cracking. In most cases, no additional lubricant would be required, except for broad surfaces where it may be necessary to use an outside nozzle to assist in cooling the work.

Warping of Thin Work when Grinding Dry. — When it is necessary to grind thin pieces and secure accurate results, many different methods of preventing warping are resorted to. One method that has been used with success is illustrated diagrammatically in Fig. 2. The piece to be ground is $\frac{1}{8}$ inch thick by $\frac{3}{4}$ inch wide by 6 inches long, and is made from steel, case-hardened. In grinding this piece, by holding it in direct contact with the face of the magnetic chuck, it is practically impossible to bring it to a uniform thickness. The method adopted, in grinding this particular piece, was to rough it out by holding it in direct contact with the magnetic chuck, leaving about 0.002 inch to remove in finishing. Two accurately ground parallel strips were then placed on the magnetic chuck with the work located on them in about the position shown. The current was then turned on for the operation of finish grinding. The first step was to true the face of the wheel, which, it will be noticed, is provided with eight diagonal notches cut in its periphery at an angle of 45 degrees with the axis of the wheel-spindle. The work was then ground by taking very light cuts with coarse side feeds and rapid table traverses, the work being turned over after taking a cut from each side. This procedure was followed until the desired thickness was obtained.

By holding the work in this manner, warping was practically eliminated, because supporting the part in this way and turning it over after each cut prevented uneven heating. A current of air is allowed to pass through freely under the work at all points, except where it contacts with the parallel strips. In addition, the diagonal notches in the wheel-face convert the wheel into a fan, assisting in cooling the work. Even with this method of holding and grinding, it would be impossible to get the piece absolutely flat without inverting it at every cut. This method, of course, is not recommended for manufacturing purposes, as the expense would be prohibitive, but this illustration is given simply to show how a thin piece of work can be ground accurately when it is impossible to use water. It will be understood that very light cuts must be taken.

Figs. 3 and 4 show another method of holding thin work to prevent warping when grinding. In this case, the work being ground is a steel plate 0.050 inch thick by $\frac{3}{8}$ inch wide by $1\frac{1}{16}$ inch long, which must be ground parallel to a limit of 0.0005 inch in thickness from end to end. The method of grinding these pieces was to arrange forty-eight of them on a Heald 6- by 8-inch rectangular magnetic chuck in the manner shown in Fig. 4. Instead of placing the chuck on the grinding machine table with the magnetic poles parallel with the axis of the wheel-spindle, the position was reversed, so that the poles were at right angles to the axis of the wheel-spindle. The pieces were then arranged in double rows butted together and overlapping the non-magnetic surfaces in the manner illustrated. While this

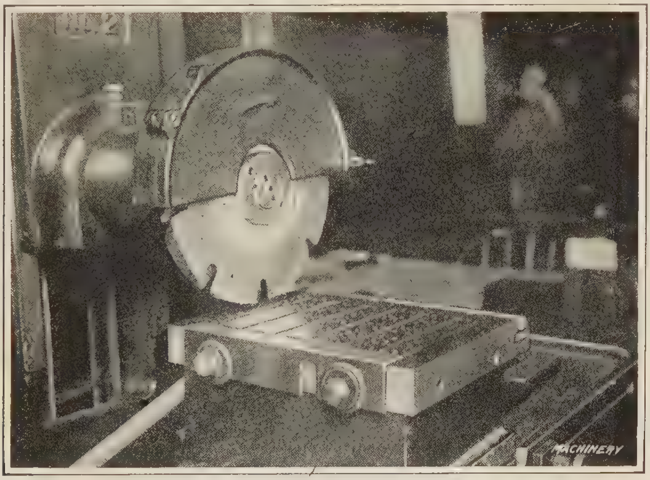


Fig. 3. Forty-eight Steel Plates 0.050 Inch Thick held on Magnetic Chuck for Grinding

arrangement, to a certain extent, reduced the strength of the magnetic flux, it made possible the holding down of the pieces with an equal pressure for their entire length. In order to prevent undue heating, a wheel of the shape shown in Fig. 3 was adopted. The efficiency of this method is proved by the fact that 1320 pieces were ground to the limits required in 30.6 hours, the time for grinding each chuck load being a little over an hour.

Holding Warped or Sprung Work. — If a thin or light piece is warped when it comes to the surface grinding machine, considerable care must be exercised in holding it, in order to prevent distortion. For instance, if it is held on a magnetic chuck, the pull of the chuck may so distort it as to make it out of true when released. Turning such a piece over several times during the grinding will, to a certain extent, eliminate much of the variation. When grinding large thin parts with a vertical-spindle rotary type of machine, warping can be minimized by placing the work central on the chuck, using suitable stops, and grinding the first side without using any magnetic current. This operation need only be carried far enough to produce a fair bearing on one side and present a flat surface to the chuck so that the work can be held magnetically. Large thin plates

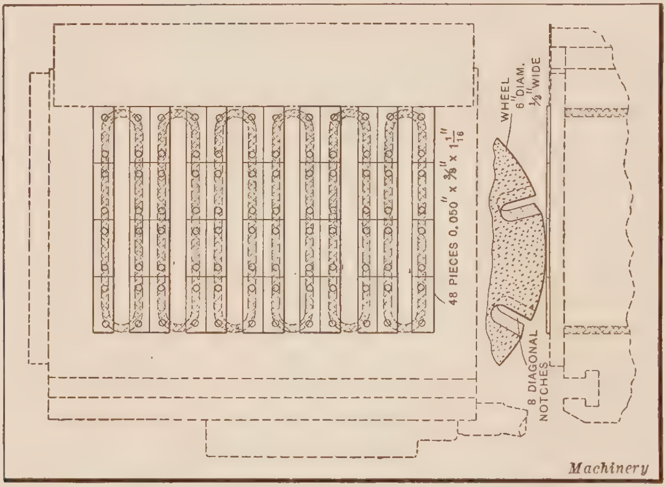


Fig. 4. Method of arranging Small Steel Plates on Magnetic Chuck

such as circular saws are often best ground without using the magnetism at all. A good general rule to follow, in practically all work that is warped or sprung out of shape, is not to hold it magnetically at all for grinding the first side but to support it in some other way, so as not to distort it.

Holding Non-magnetic Work. — When grinding brass, aluminum, and other non-magnetic materials, the work must be clamped or secured by some other means than by direct magnetism. The method generally used is to employ a vise, clamping fingers, or other work-holding fixtures for retaining the part to be ground, where the use of such devices is possible. If the work is quite heavy, it can be held on a chuck, by simply using a backing-up strip to prevent it from shifting. When the piece is in the shape of a ring or plate, and a vertical-spindle rotary type of machine is used, it can be ground by being placed centrally on the chuck; in this case the work will be held down by the wheel itself and need only be centered by stops or by a plug in the center of the hole, if there is one in the piece.

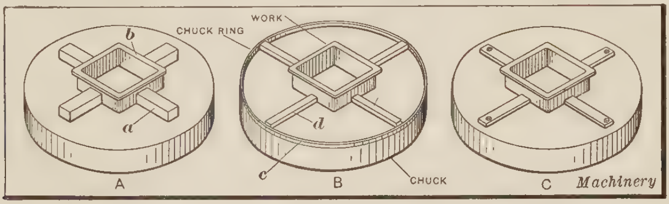


Fig. 5. Examples illustrating Methods of Holding Non-magnetic Work on Magnetic Chuck by using Strips or Stops

The magnetic chuck can sometimes be used to advantage for holding non-magnetic work by using strips or stops as shown in Fig. 5. In diagram *A*, four small steel blocks are placed and held on the magnetic chuck as illustrated, and prevent the casting *b* from shifting, enabling it to be ground. Still another method is shown at *B* where a chuck ring *c* and four pieces *d* are used for supporting the work and preventing it from shifting on the magnetic chuck. Still another method is shown at *C* where the pieces for supporting the work are clamped by bolts to the face of the chuck. This method can also be adopted when an ordinary non-magnetic chuck is used.

Non-magnetic work of box form can be held magnetically by using blocks of cast iron or steel which are placed inside the parts to be ground. The magnetic attraction of these blocks will be strong enough to hold the work, provided the thickness of the part between the blocks and chuck does not exceed about $\frac{1}{16}$ inch. This same method has been successful for holding thin pressed steel boxes, the sides of which were so high that the boxes could not be held rigidly enough for grinding the upper edges without placing the magnetic blocks inside.

Wheel Speeds for Surface Grinding. — The grinding wheel speeds for surface grinding are generally less than those for external cylindrical grinding and vary between 3000 and 5000 feet per minute. The speeds are generally higher for a disk wheel than for a cylinder or ring wheel, the latter grinding on the edge instead of on the circumference. On a surface grinding machine of the type shown in Fig. 3, which has a disk wheel, the speed is usually about 5000 feet, whereas on a Blanchard vertical surface grinding machine, the wheel speed is about 4000 feet per minute. On the Heald rotary surface grinder, which has a disk wheel, the speed is about 5000 feet per minute.

Work Speeds and Feeds. — The feeds and work speeds to use for surface grinding depend largely on the method of applying the wheel to the work. On the type of surface grinding machine which operates on the principle shown at *A* in Fig. 1, the traverse speed of the table varies from 25 to 50 linear feet per minute, depending upon the material, the width of face of wheel used, and the depth of cut taken. Usually, the cross-feed is equal to $\frac{1}{2}$ or $\frac{3}{4}$ the width of the grinding wheel-face, but this lateral feed is varied according to the finish required. When the piece is to be finished in one cut, with a wheel about $\frac{3}{4}$ inch wide, and a fairly smooth surface is required, a feed of from $\frac{1}{16}$ inch to $\frac{1}{8}$ inch per traverse is generally used. The depth of cut varies from 0.0005 to 0.003 inch.

When using machines which operate on the principle shown at *B*, Fig. 1, if the work is less than 10 inches in width, the wheel is not fed laterally but the work is traversed back and forth under the wheel, the complete surface being finished in one cut. On a machine of this kind, the table traverse varies from 25 to 50 linear feet per minute and the depth of cut from 0.0005 to 0.003 inch per traverse.

On surface grinding machines of the type indicated by diagram *C*, Fig. 1, the table is traversed at a rate of from 25 to 50 linear feet per minute and the cut varies in depth from 0.001 to 0.005 inch per traverse. When this type of machine is used for large castings, naturally, a heavier cut is taken than when the work is of a finer and more accurate nature.

Where the grinding is done on a machine of the type illustrated at *D* in Fig. 1, the table is traversed, and, usually, the ring or cylinder wheel used covers the entire width of the surface being ground. When this is the case, the two points to consider are the table traverse and the down feed of the wheel. The table traverse varies from 15 to 50 linear feet per minute and the down feed from 0.0005 to 0.002 inch per traverse.

On surface grinding machines of the type indicated at *E*, Fig. 1, where the work and wheel both rotate but are not traversed, generally, the down feed of the wheelhead varies from 0.001 to 0.002 inch per revolution of the work-table; the table speeds vary greatly, depending upon the type of machine and the nature of the work. The grinding wheels used on machines of this design are not adapted to deep cuts, and more stock can be removed, with less wheel wear, by means of light cuts and comparatively fast speeds than by heavy cuts and slow speeds. The cut, however, should be deep enough to keep the wheel cutting freely and feeds as fine as 0.0002 to 0.0004 inch should be avoided, as, on most work, they tend to make the wheel glaze.

In determining the correct table speeds and depth of cut to use on the Blanchard vertical surface grinder, a down feed of about 0.001 inch should be used to start with. If the wheel glazes, rough the face with a carborundum block held in the hand, and try the wheel again, using the next lower table speed with slightly increased down feed. If the wheel appears to be too soft and wears away too rapidly, increase the table speed and decrease the down feed. Obviously, a down feed of 0.002

inch with a table speed of 6½ revolutions per minute removes the same amount of stock per minute as a down feed of 0.001 inch with a table speed of 13 revolutions per minute. Varying the speed and feed to improve the cutting action of the wheel need not, therefore, change the rate of cutting. It should be clearly understood, however, that, in order to obtain satisfactory results, the wheel must be suited to the work.

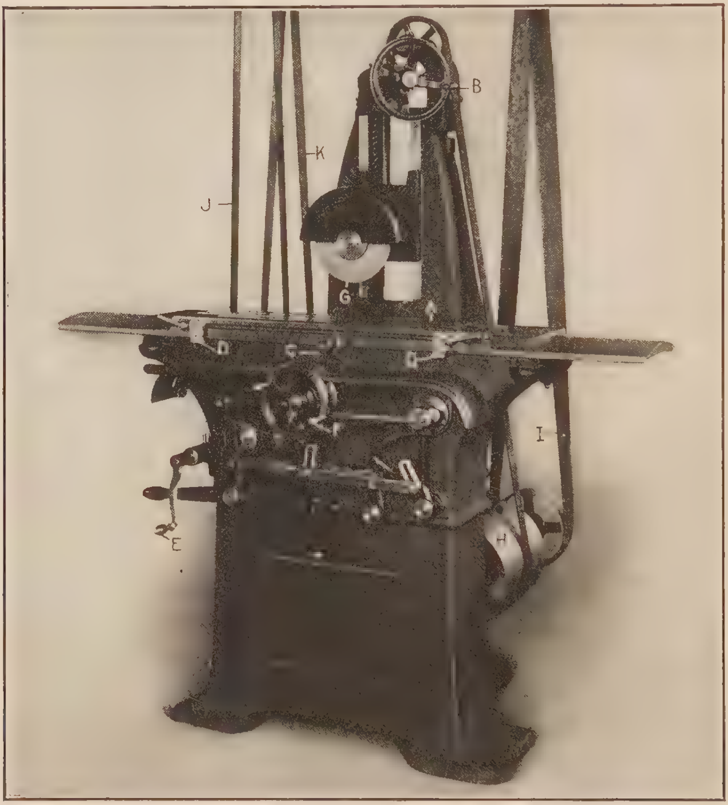


Fig. 6. Walker Surface Grinder of Reciprocating Type

Surface Grinder of Reciprocating Type. — Fig. 6 shows a plain surface grinder of medium size which operates on the principle illustrated by diagram *A*, Fig. 1. The part to be ground is attached to table *A* and the grinding is done by wheel *G* which can be adjusted to the proper height by handwheel

B. The stroke of the table is controlled by the position of dogs *D* and D_1 which operate the reverse lever *C*. As the table reciprocates, the wheel, with the column which supports it, feeds laterally at each end of the stroke. The movement of the table and the lateral feeding movement of the wheel are automatic when grinding but they can be effected by hand for making adjustments. Crank *E* is for traversing the table and wheel *F* operates the hand cross feed. The belt, which drives the grinding wheel, connects with pulley *H*, and the latter is driven by belt *I* from an overhead shaft. The reciprocating movement of the work-table is derived from the belts *J* and *K*. The lever *C* not only reverses the table but also operates the mechanism for feeding the grinding wheel laterally. The traversing motion of the work-table can be stopped automatically, when the wheel has fed across the part being ground, by means of a trip mechanism.

Some surface grinders which grind with the periphery of the wheel, like the machine illustrated in Fig. 6, are designed along the lines of an ordinary planer; in fact, the construction is almost identical except that a grinding wheel is mounted on the cross-rail instead of a tool-head. When this type of machine is in operation, the work-table reciprocates and the wheel feeds laterally across the surface to be ground.

Open-side Surface Grinding Machine. — Experience has shown, that, in the operation of grinding wheels, the smaller the arc which is in contact with the work, the more efficient the operation of the wheel becomes, and, as a result, it is advisable to use wheels of small diameter, especially when grinding plane surfaces, as the arc of contact, in such cases, is much greater than when round work is being ground. With a large arc of contact, the opportunity for the chips to escape is reduced. This results in heating, undue power consumption, and general inefficiency. When, for any reason, the chips cannot escape freely, a satisfactorily finished surface cannot be produced.

The Norton open-side grinding machine illustrated in Fig. 7 is a reciprocating type and is designed for grinding plane surfaces. In order to obtain the most satisfactory results, the periphery of the smallest wheel that is practical for the work in hand is used. The machine is intended to carry wheels 14 inches in diameter, and, for the usual class of work handled, the wheel should have a 6-inch face. For special work, wheels of different widths can be used. This machine operates on the principle illustrated by diagram *B*, Fig. 1. The wheelhead can be raised, so that the distance between the surface of the table and a 14-inch wheel is 17 inches; this provides for the use of a magnetic chuck or supplementary table, when necessary.

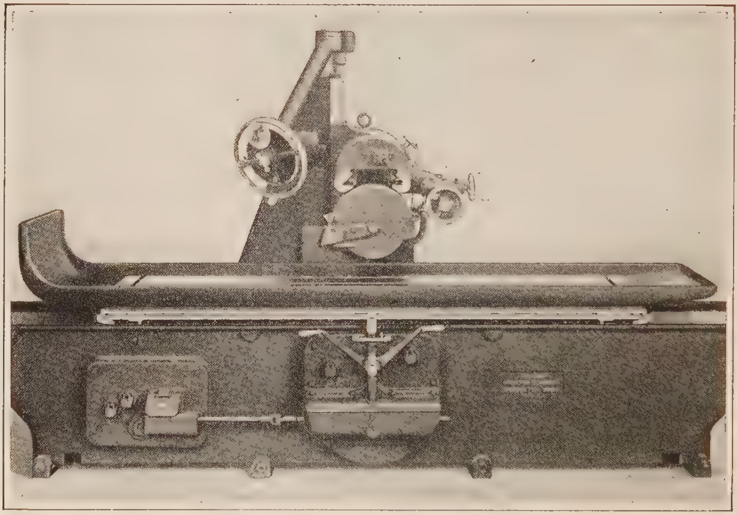


Fig. 7. **Norton Open-side Grinding Machine**

The countershaft is located in the machine base, so that the machine is self-contained. Power is transmitted to this countershaft by a belt running from the motor which is placed at the side of the machine. The grinding wheel is carried on a cross-slide operating at right angles to the travel of the table, and, in order to secure the high rate of production that is made possible by the wide wheels used on this machine, no automatic feed of the wheel has been provided. A hand traverse has been designed for locating the grinding wheel, in order to utilize the full width of the wheel-face. Provision is also made for a slower traverse of the wheel when truing its face, this traverse being obtained through worm-gearing. The cross-slide is carried on a vertical-slide which is raised and lowered on the column by means of a small motor. For short distances, the vertical traverse is obtained by means of a handwheel on a shaft geared to the vertical traverse screw.

Horizontal Face Grinding Machine. — A face grinding machine is illustrated in Fig. 8. This type operates by traversing the work past the face of ring wheel *G*, as previously explained in connection with diagram *C*, Fig. 1. The part being ground is clamped to table *A* which has an automatic reciprocating movement. The length of the stroke is regulated by dogs (not in place) which engage reverse lever *C*. The wheel has an adjustable automatic power feed and both the wheel and worktable can be moved by hand. This particular machine is driven by a motor *D* which is connected to the wheel-spindle by a belt.

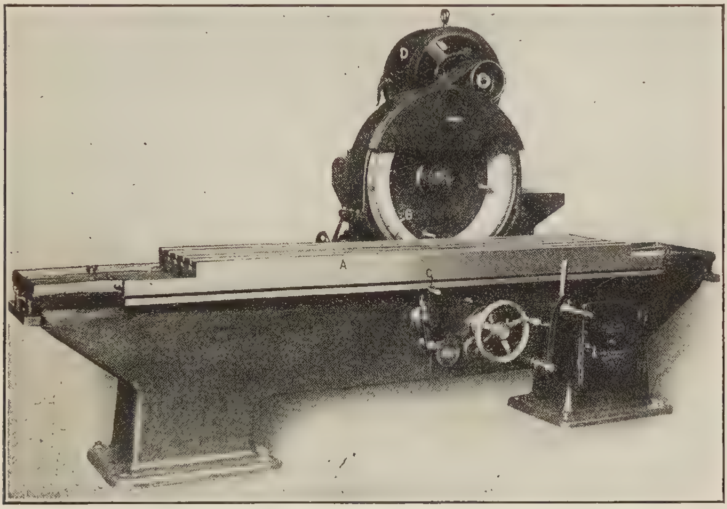


Fig. 8. Diamond Motor-driven Face Grinding Machine

The face grinder has some advantages over the type of machine using a wheel that grinds on the periphery. In fact, the advantages are similar to those which a face milling cutter has over an axial milling cutter. In the first place, the power consumption is less and plane surfaces are produced with fewer passes of the grinding wheel. The radius of a cup-wheel also remains the same until it is worn out, instead of changing constantly, as with a disk wheel. The type of face grinder shown in Fig. 8 is generally used for grinding quite heavy parts and it is especially adapted to that class of work which can be held to better advantage when the surface to be finished is in a vertical plane. For example, the ends of rather long castings, such as machine legs, etc., can easily be ground on this style of grinder, because the work can be clamped to the table of the machine in a horizontal position. Evidently, it would be impracticable to grind work of this class on a machine having a vertical spindle, because the castings would have to be held in an upright position. The horizontal face grinder is used in locomotive shops for truing or finishing the bearing surfaces of guide-bars and can be employed to advantage for many other grinding operations.

Rotary Vertical-spindle Surface Grinder. — The type of surface grinder shown in Fig. 9 is designed for rotary grinding, the principle of its operation being indicated by diagram *E*, Fig. 1. A cup-wheel *G* is carried by an upper slide *B* and the work is held on a rotary magnetic chuck *C* mounted on lower slide *D*. The wheel-spindle is driven from a horizontal shaft at the rear by a quarter-turn belt, as shown, whereas the work-table is driven from drum pulley *E*. When the machine is in operation, the wheel is fed down against the work, until the latter is finished to the required thickness, by operating hand lever *F*. The wheel slide is fed against a positive stop and the thickness of the work is varied by adjusting the lower slide which is equipped with a vertical feed-screw. This screw is operated by handwheel *H* which is graduated to thousandths of an inch. When the lower slide has been set, its position is not changed for successive operations, except to compensate for wheel wear.

This machine can be used for concave grinding, in which case, the knee supporting the work-table is tilted to the required angle. Work having a concave surface is not held directly against the magnetic chuck but on an auxiliary plate. The magnetic power of the main chuck is transmitted through this auxiliary plate, the upper surface of which is shaped to suit the surface of the work. The use of an auxiliary plate in connection with the grinding of a milling saw is illustrated in Fig. 10.

After the saw is ground concave on one side, it is held for grinding the opposite side on a plate *A* having a convex face. If the saw were held for grinding the last side against the flat face of the regular chuck, it would be sprung down in the middle so that both sides would not be finished alike or to the same concavity. Fig. 11 shows how a number of parts can be ground simultaneously on a rotary surface grinder. In this instance, three castings are arranged in a group on the magnetic chuck in such a way that they support each other, to some extent, while the top surfaces are being ground flat. These views indicate, in a general way, the kind of work that is ground on a machine of this type.

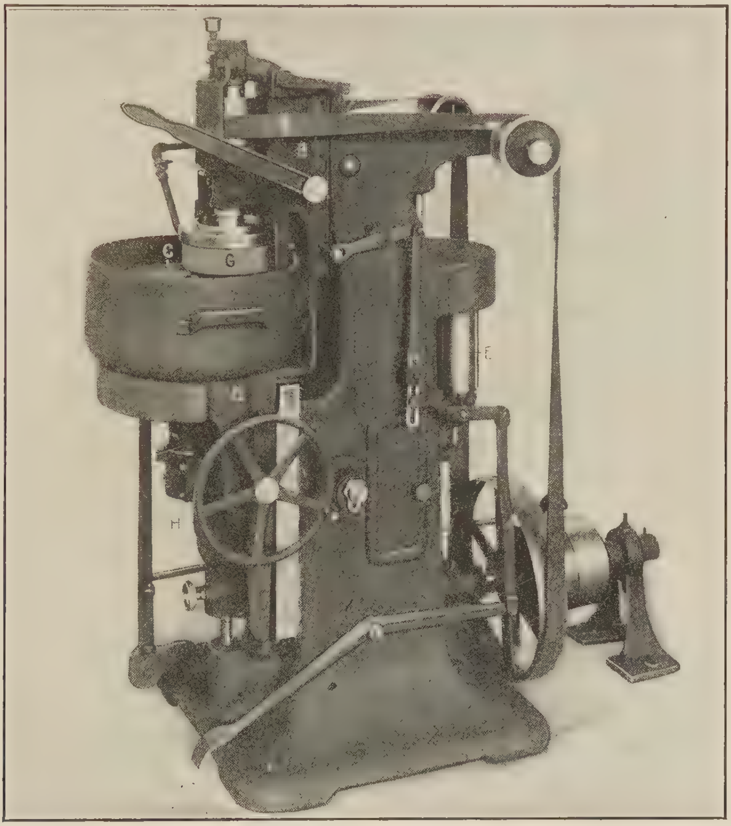


Fig. 9. Walker Rotary Surface Grinder

Rotary Disk and Surface Grinder. — The type of surface grinder shown in Fig. 12 is especially adapted for grinding disk-shaped parts or the sides of piston rings. As will be seen, the disk form of grinding wheel is used; this wheel is mounted on the end of a horizontal spindle which is carried in a ram or slide *A* that feeds the wheel across the work. The work-table *B* is of the rotary type and is equipped with a magnetic chuck. When a surface is being ground, the wheel feeds horizontally, and, by means of an accelerating mechanism, the speed of the work is automatically increased as the wheel approaches the center and the lateral feed of the wheel remains constant per revolution of the work Inversely, when the wheel recedes from the center, the speed and feed is automatically retarded. The horizontal feed of the wheel is at the rate of $\frac{3}{16}$ inch per revolution of the work. If the machine were not equipped with this accelerating mechanism as the wheel approached the center of the work, the wheel would follow a spiral path of ununiform pitch; consequently, the efficiency of the grinding operation would be reduced and the wheel, having

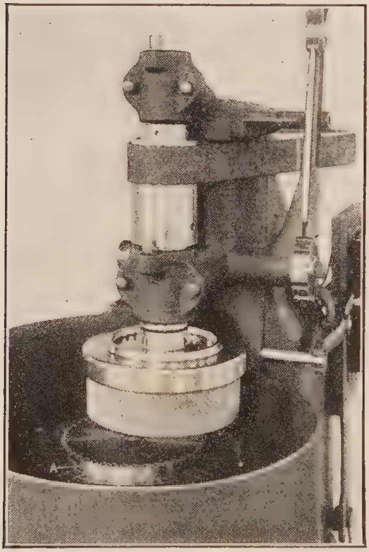


Fig. 10. Grinding Side of a Saw Concave

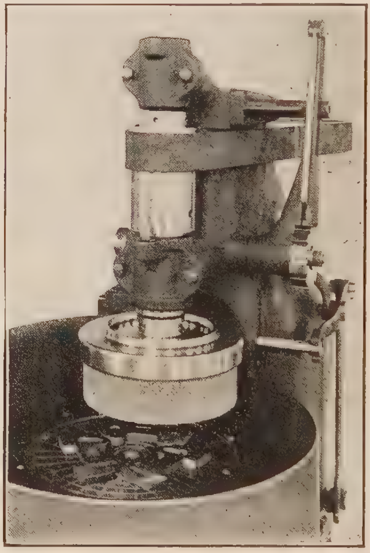


Fig. 11. Grinding Three Castings Simultaneously

less work to do near the center of the disk, would tend to cut deeper, thus producing a slightly concave surface.

The work-table may be adjusted vertically by handwheel *C* and has an automatic feed which can be operated at both ends of the stroke of the ram. This automatic feed is derived from dogs on the ram which transmit motion to the vertical feed-screw through the ratchet-and-pawl mechanism on the opposite side of the machine. The belt pulley on the grinding-wheel spindle is in the form of a drum of sufficient length to provide for the full stroke of the ram. This drum is driven from the main shaft located in the base of the machine. The point of reversal for the ram is controlled by adjusting the dogs *D* and

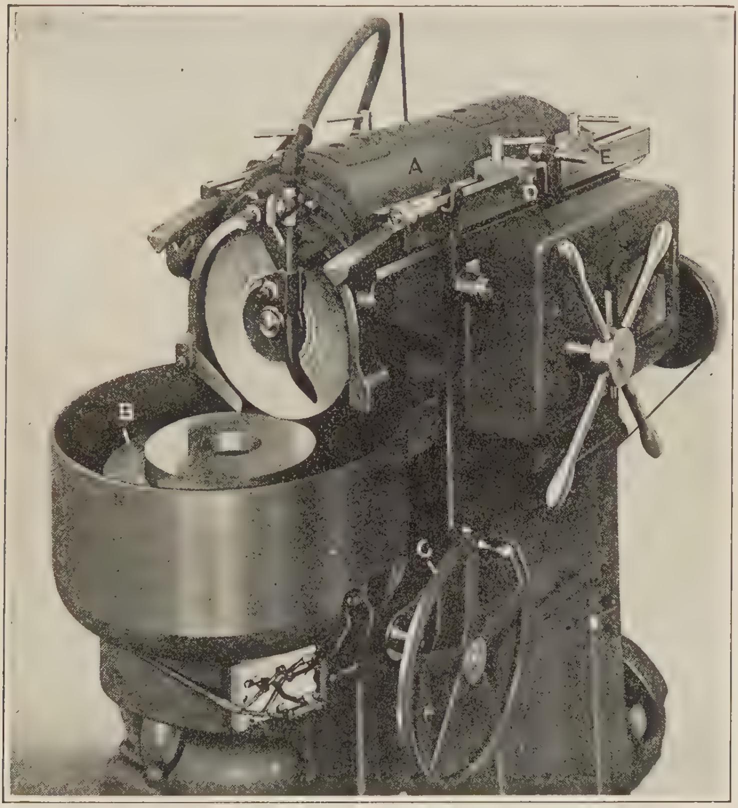


Fig. 12. Walker Rotary Disk and Surface Grinder

E. A scale is provided indicating "hole diameters" and "disk diameters," so that one dog may be set to reverse the ram when the wheel reaches a hole at the center of a disk, while the other dog is set to reverse the ram when the wheel has reached the outer edge or periphery of the work. The knee carrying the work-table is pivoted to the vertical-slide, so that it can be tilted for grinding concave or convex surfaces. The machine has a pump for supplying cooling water to the wheel through the pipe shown in the illustration.

Vertical Surface Grinders. — Fig. 13 shows a surface grinder of the vertical type. The grinding is done by ring or cup-wheel *G* which covers the full width of the work. With this machine, the work can be given either a reciprocating or rotary motion, depending upon the shape of the part being ground. For grinding rectangular surfaces, or parts that should move in a straight line beneath the wheel, the table *A* is given a reciprocating movement, the length of which is controlled by dogs in the usual manner. On the other hand, the sides of saws, rings, or flat disk-shaped parts are rotated while being ground by placing them on a rotary chuck which is mounted on the grinder table, the table remaining stationary.

When the rotary chuck is not in use, this machine operates as illustrated by diagram *D*, Fig. 1. The grinding wheel and its spindle is carried by a head *B* which can be fed vertically on the face of the column. The vertical feed can be operated automatically or by hand and disengaged automatically at any pre-determined point. The reciprocating table can be moved by hand, if desired. This grinder is equipped with a pump for supplying cooling water to the wheel. The water is pumped into the hollow spindle, at the top, and passes down to the inside of the grinding wheel, after which it is driven outward by centrifugal force between the wheel and the work. An outside stream of cooling water is also provided and the table is surrounded by a water guard *C* which prevents the water from flying about.

The vertical type of grinder can be used advantageously for grinding long rectangular surfaces, disk-shaped parts (by using the circular attachment), and it is very efficient for grinding a number of small castings simultaneously. When several parts are to be ground at the same time, they are grouped on the table of the machine or on a magnetic chuck, so that the wheel will grind each casting as the table feeds along. It is comparatively easy to hold several small castings on a grinder of this type, because they are placed horizontally on the machine, and, as the wheel operates on the top surfaces, the pressure of grinding is mostly downward against the table and bed, which provide a solid unyielding support. This type of machine is used extensively for grinding from the rough; that is, castings or forgings are finished by grinding without any preliminary machining operation, such as planing or milling. This practice

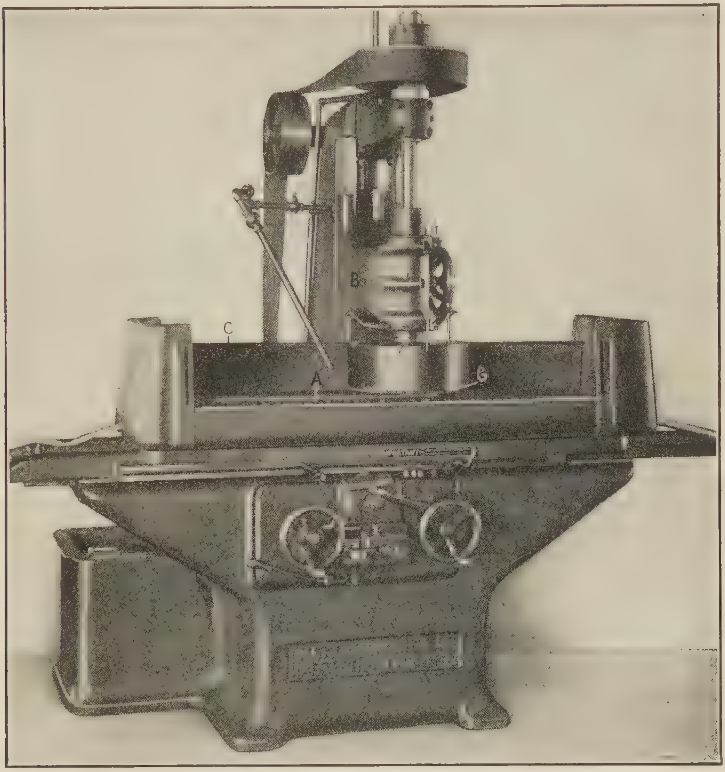


Fig. 13. Pratt & Whitney Vertical Surface Grinder

is followed when it is not necessary to remove very much metal.

This machine, for certain classes of work, is equipped either with duplex or quadruplex rotary magnetic chucks, the latter type being illustrated in Fig. 14. A double chuck, like the single design, may be tilted for grinding concave or convex surfaces, whereas the quadruplex chuck is only used for plane or flat surfaces. Both the rectangular and rotary magnetic chucks are waterproof. The single rotary chuck is made either plain or magnetic.

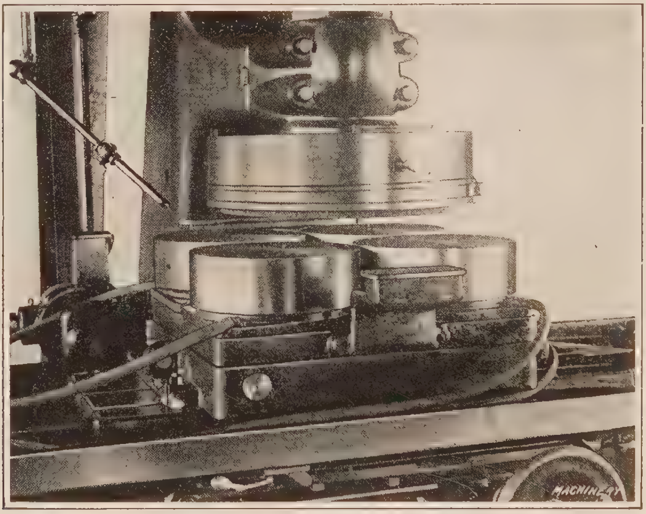


Fig. 14. Quadruplex Rotary Magnetic Chuck

Another vertical surface grinding machine that operates on the principle shown by diagram *E*, Fig. 1, is illustrated in Fig. 15. This is a Blanchard machine and is motor-driven. The wheel-spindle is driven by a motor of the alternating-current type. The gear-box at *A*, through which table *B* is rotated, provides for eight changes of speed, varying from 5 to 44 revolutions per minute. The chuck is usually started and stopped by means of a hand lever on the gear-box. The foot treadle *C* is used for moving the chuck through part of a revolution when placing the work in position for grinding. The table is brought into position under the wheel, after the work has been located in the chuck, by operating turnstile *D*. The correct working position for the table is shown in Fig. 16.

The vertical feed for the wheelhead can be effected either by hand or power and is varied by adjusting the feed variator *E*. Feed-wheel *F* is graduated in such a manner that a movement of $\frac{1}{2}$ inch on the circumference of the wheel means a down feed of 0.001 inch. Down feeds of the wheelhead can be varied from 0.0002 inch to 0.005 inch per revolution of the work-table by increments of 0.0002 inch. The down feed is also provided with an automatic stop which can be set to stop the feeding movement as soon as the desired thickness on the work is obtained. The cooling water is supplied by a centrifugal pump.

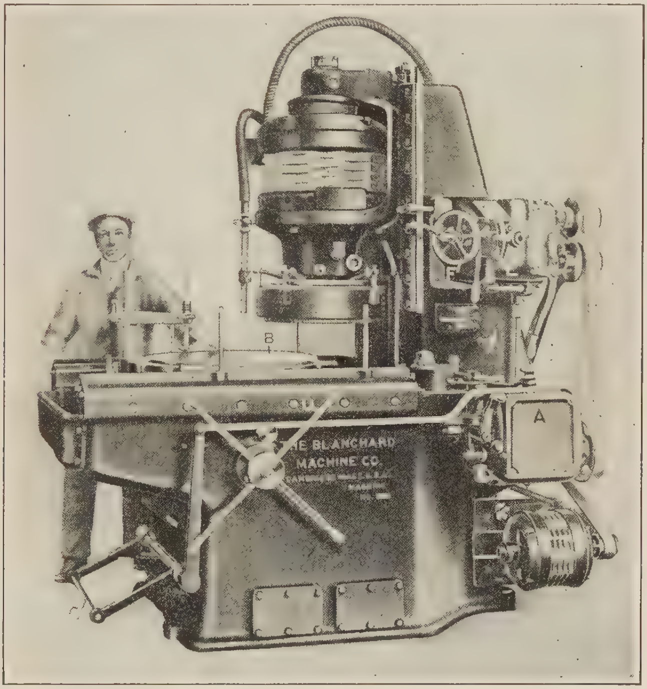


Fig. 15. Blanchard Vertical Surface Grinder

Mounting Wheels on Blanchard Surface Grinder. — The grinding wheels used on the Blanchard motor-driven vertical surface grinders are 18 inches in diameter, 5 inches deep, and with rims varying from 1 to $1\frac{1}{2}$ inch thick, depending on the work to be ground. Of the 5 inches total depth, $3\frac{15}{16}$ inches can be used. As shown in Fig. 17, the grinding wheel *A* is cemented into a cast-iron retaining ring *B*, which, in turn, is held to a flange on the lower end of the vertical spindle. There are several methods of mounting wheels of this type. One is to mix equal parts of Portland cement and sand with water to the consistency of a thin paste; then wet the wheel thoroughly all over and spread a thin layer of the cement paste on the end that is to go next to the chuck. The next step is to remove all dirt and grease from the inner surfaces of the retaining ring and place the wheel centrally in the ring. Next fill the space between the wheel and the iron ring with the cement paste, using a thin piece of metal to ram it in. All surplus cement should be removed from the outside of the ring, and then the wheel should be covered with wet cloths and placed in a covered box or barrel. The wetting of the wheel before cementing and keeping it damp while the cement sets are very important. Wheels should be allowed to set two days, or more, varying with the brand of cement used. If the inside of the ring wheel has not already been "waxed," it should be covered with paraffine wax painted on hot, to prevent any trouble from the water spraying.

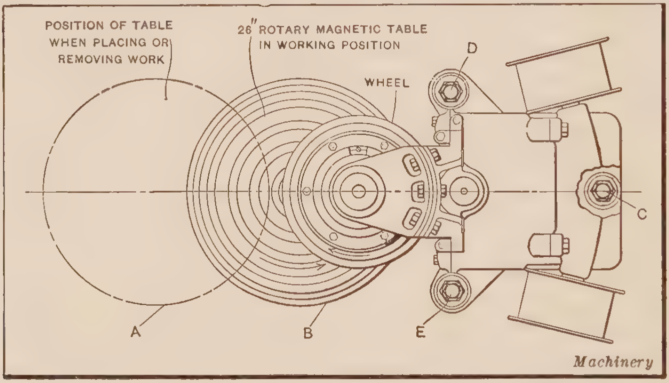

POSITION OF TABLE WHEN PLACING OR REMOVING WORK
26" ROTARY MAGNETIC TABLE IN WORKING POSITION
WHEEL
D
C
A
B
E
Machinery

Fig. 16. Plan View showing Relative Positions of Work-table and Grinding Wheel of Blanchard Machine

Another method of cementing in cylinder or ring wheels, which is much quicker than the one just described, is to use melted sulphur. The wheel and ring are cleaned, as before, then the sulphur is melted and poured into the space between the wheel and ring. The sulphur hardens as it cools and the wheel may be used within a short time after the sulphur has been poured in.

Truing Wheels on Vertical Machine. — For truing the wheel used on the Blanchard vertical surface grinder, a stick of special carborundum, mounted in a cast-iron holder, is used. This is applied to the wheel by placing the holder on the magnetic table and sliding the table in and out, thus traversing the carborundum stick across the face of the wheel.

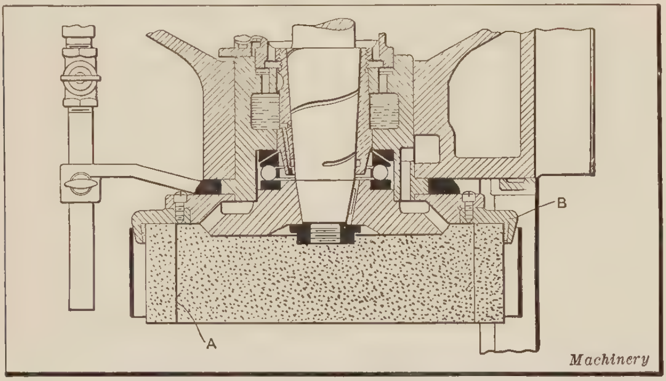


Fig. 17. Sectional View of Grinding Wheel and Lower Spindle Bearing on Blanchard Machine

A new wheel should be trued before using, but after this first truing has been done, the wheel should not be touched until it glazes. As soon as glazing occurs, the wheel-face should be roughed up with a piece of carborundum held in the hand. A wheel that requires this treatment too often is too hard or too fine for the work and should be changed. The right wheel for the job will run until worn out without dressing. It should also be remembered, that, in a vertical surface grinder of this type, the wheel-face does not need to be kept flat, in order to secure flat work.

Relation of Table to Grinding Wheel. — For loading the magnetic table or chuck on a Blanchard vertical surface grinder, the table is moved out from under the grinding wheel, as shown by the dotted line *A* in Fig. 16. The work is then placed on the magnetic chuck, after which the table is moved in until the outer rim of the wheel coincides with the central axis of the work-table, as shown at *B*. The table and work are then rotated in the directions indicated by the arrows.

For straight plain surface grinding, the spindle should be set absolutely square with the chuck face, so that the wheel touches the work on both sides; when the wheel is properly set, parts can be ground within limits of 0.0003 inch without difficulty. There are some classes of work, however, for which it is necessary to set the wheel-spindle at an angle to the face of the work-table, as when grinding the concave sides of circular saws, etc. To make this adjustment, the rear column support *C*, Fig. 16, is provided with a graduated washer. To set the head for concave work, the three column support bolts *C*, *D*, and *E* should be loosened, but the two front washers should not be disturbed. The setting of the rear washer should be noted before changing; then turn this washer to the right until the spindle is inclined the desired amount and tighten all the bolts firmly before starting the machine. A slight adjustment of the rear support, or any other, may be made by simply loosening the bolt which is to be adjusted.

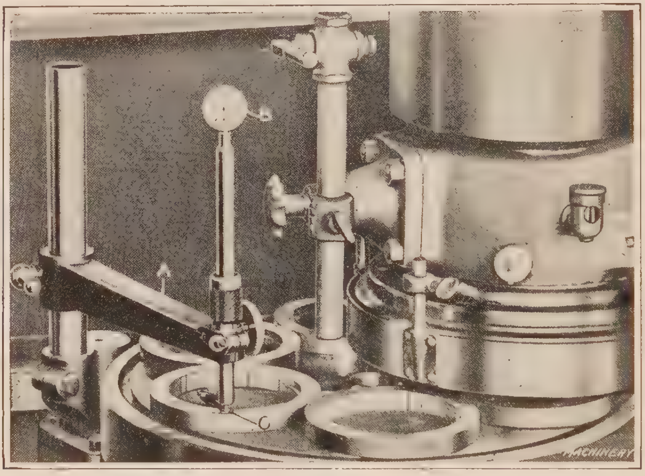
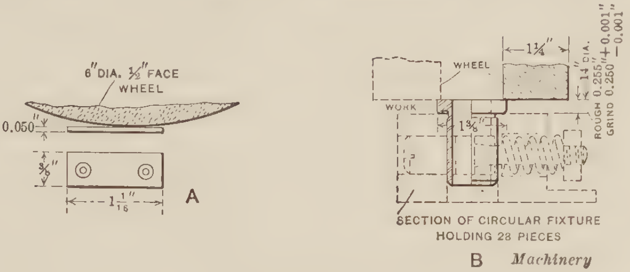


Fig. 18. "Continuous Reading Caliper" applied to Blanchard Machine



A

Work: — Pivot plate made from 0.20 per cent carbon, cold-rolled strip steel, casehardened 0.012 inch deep.

Operation: — Grinding both sides with Norton (vitrified) alundum wheel; grain 38–46, grade G; 6 inches in diameter, ½ inch face; wheel speed, 3183 R.P.M. — 5000 feet surface speed; provided with eight diagonal notches around its periphery; amount removed from each side, 0.0015 to 0.002 inch.

Remarks: — Table is traversed back and forth by hand and also in and out by hand; 48 pieces held at one time on a Heald 6- by 8-inch flat magnetic chuck; pieces arranged along or parallel with magnetic poles instead of spanning them; four traverses to complete each side; 250 pieces turned out per each truing of wheel; production, 1320 in 30.6 hours; machine used, No. 2 Brown & Sharpe surface grinding machine.

B

Work: — Bushing for steering spindle, 0.15 per cent carbon open-hearth steel, carbonized and hardened.

Operation: — Surface grinding large end with a Norton (vitrified) alundum wheel; grain 24, grade L; 14 inches in diameter, 1¼ inch face; speed, 1400 R.P.M. — 5126 feet surface speed; table speed, 100 R.P.M.; head travel or traverse speed, 42.5 linear inches per minute; amount removed, 0.007 to 0.010 inch.

Remarks: — Wheel is traversed back and forth across work, which is held in a special ring fixture carrying 28 bushings; production, 4000 in nine hours; machine used, Heald rotary surface grinding machine.

Fig. 19. (A) Surface Grinding Operation on Steel Plates 0.050 Inch Thick. (B) Grinding Bushing Flanges on Rotary Surface Grinder

Measuring Work on Surface Grinding Machines. — The method of measuring work on surface grinding machines depends entirely on the type of machine. On machines having a wheel-head, which is lowered or elevated by means of an adjusting screw, the graduated index on the wheel is generally used as a guide for grinding the work to approximately the required thickness. The work is then removed from the chuck and measured, from time to time, until the desired thickness has been obtained. After several pieces have been ground, it is possible to grind very close by means of the index wheel, as the only variation is due to the wear of the wheel.

On the Blanchard vertical surface grinder, a device known as a "continuous reading caliper" is applied directly to the work, and readings are taken continuously as the work-table rotates. This attachment consists of an arm *A*, as shown in Fig. 18, which is clamped to a vertical post and carries, in its front end, a spindle and other members that operate the needle of a dial *B*; this dial indicates the exact amount, in thousandths of an inch, by which the work thickness varies from the finished size. The reading is secured through a hardened-steel button *C* that rests on the work and is connected to the gage. To set the caliper, the button is placed in contact with a sizing block or finished piece that is on the table, and the dial of the gage head is revolved until the zero line coincides with the needle.

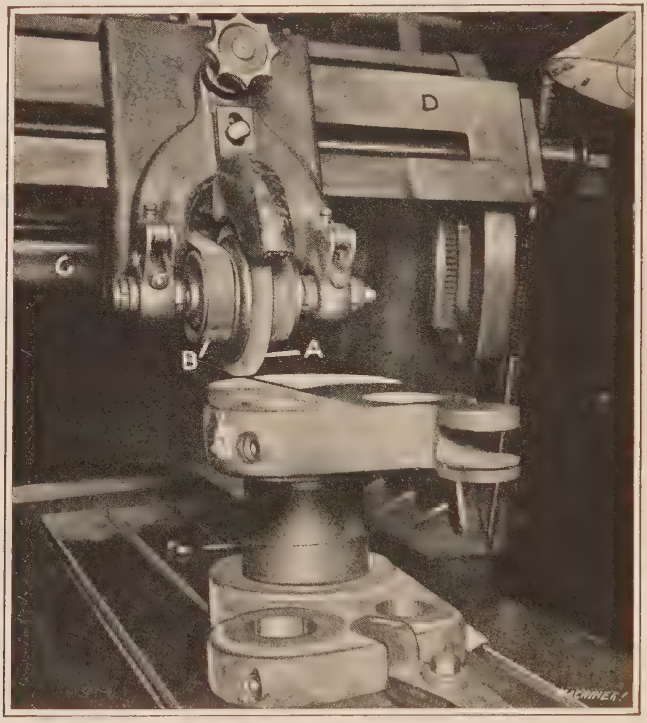
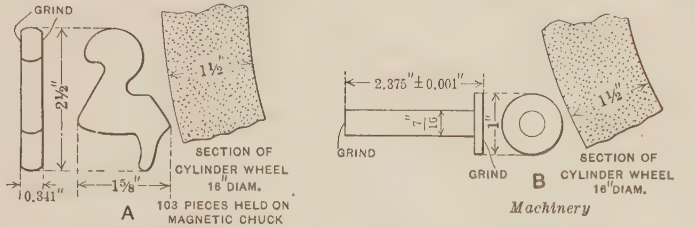


Fig. 20. Planer Type of Surface Grinding Machine

Examples of Surface Grinding. — The examples of surface grinding, shown in the following illustrations, indicate, in a general way, the kind of work that is finished on surface grinding machines.



Machinery

A

Work: — Rifle hammer, soft steel forging, not hardened.

Operation: — Grinding both sides from the rough with an American (silicate) corundum wheel; grain 58–24, grade ¾; 16 inches diameter, 1½-inch rim; speed, 1000 R.P.M. — 4190 feet surface speed; table speed, roughing, 17 R.P.M. — finishing, 5 R.P.M.; down feed of wheel, 0.001 inch per revolution of table; amount removed from each side, 0.025 inch.

Remarks: — 103 of these parts are held at one time on Blanchard magnetic chuck between two retaining rings; grinding time, 8 minutes; handling time, 12 minutes; limits, plus or minus 0.0005 inch; production, 300 pieces per hour; machine used, Blanchard high-power vertical surface grinder.

B

Work: — Gas engine valve push-rod, vanadium steel drop-forging, heat-treated.

Operation: — Surface grinding both ends from the rough with an American (silicate) corundum wheel; grain 30; grade 1–W; 16 inches diameter, 1½-inch rim; speed, 1000 R.P.M. — 4190 feet surface speed; table speed, 17 R.P.M.; down feed of wheel, 0.0015 inch per revolution of work-table; amount removed from each end, 0.010 inch.

Remarks: — 104 of these parts are held at one time on a Blanchard magnetic chuck by means of a special clamping fixture; handling time is greatly reduced by providing three fixtures; production, 720 pieces per hour; machine used, Blanchard high-power vertical surface grinder.

Fig. 21. (A) Data for Grinding Rifle Hammers and (B) Gas Engine Valve Push-rods on Vertical Surface Grinder

For grinding large machine parts, such as milling machine tables, etc., the type of surface grinding machine shown in Fig. 20 is sometimes used. This particular machine carries a disk wheel *A* which is driven from the overhead works by means of the pulley *B* from a drum pulley *C*. The grinding wheelhead is held on the rail *D* and can be moved back and forth by means of power or hand feed, the power feed being effected in practically the same manner as on a planer. The rail swings on an arc, because the belt would be tightened and loosened if the rail were adjusted up and down in a vertical position. The point from which the rail swings is the axis of the drum pulley *C*. When grinding parts on a surface grinding machine of the planer type, the work is generally clamped direct to the table by means of bolts, as illustrated, or is held up against angle-plates, the method depending entirely upon the kind and shape of work to be ground.

For the operation shown in Fig. 20, a carborundum wheel of grain 36 and grade P or M is used; the wheel is 9 inches in diameter and is fed across the work at the rate of $\frac{1}{16}$ inch per traverse. The work-table operates at a speed of 35 linear feet per minute and from 0.005 to 0.007 inch is removed by grinding.

The grinding of certain rifle parts can be done satisfactorily on the vertical surface grinder because such a large number of pieces can be held at one time and special fixtures are not required for many of the parts. By the method illustrated in Fig. 22, 103 rifle hammers are ground simultaneously. These hammers are held on a magnetic chuck by simply using two retaining rings, one inside the group of pieces and one outside. This brings up a point regarding the vertical surface grinder that is worthy of attention. For a large number of parts, a surface grinder of this type requires few fixtures. Simple rings of sheet steel may be laid around the groups of pieces to be ground, and, even if the parts are of irregular shape, it is usually possible to make a very simple magnetic fixture.

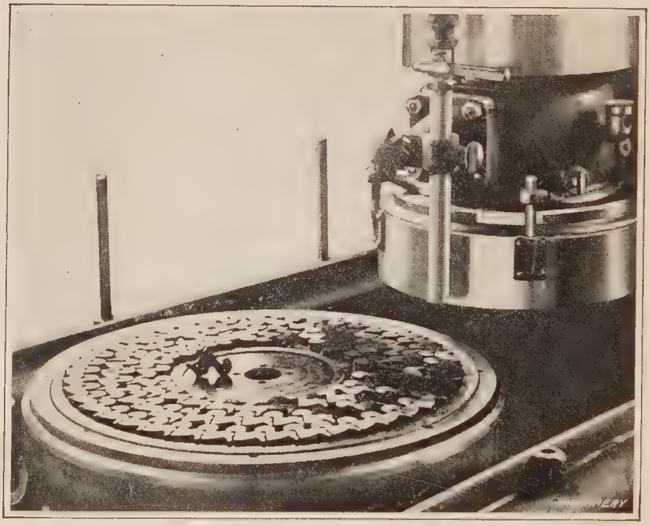


Fig. 22. Over 100 Rifle Hammers being ground Simultaneously

Referring to *A* in Fig. 21, it will be seen that the rifle hammer is made from a soft steel forging and is not hardened. The speed of the table is changed twice for finishing the surface. For roughing, a speed of 17 R.P.M. is used, whereas, for finishing, the rotative speed of the table is reduced to 5 R.P.M. This enables the same wheel to be used for both roughing and finishing operations and gives the desired finish. The production, on this particular part, is at the rate of 300 pieces per hour.

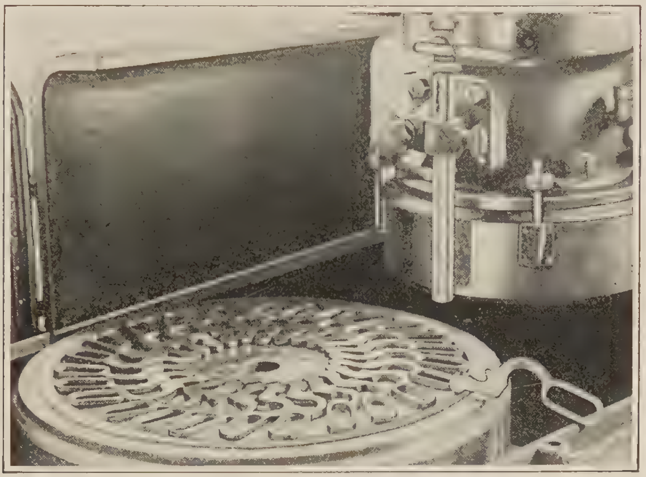


Fig. 23. Grinding Thirty-four Repeating Rifle Levers Simultaneously on Vertical Machine

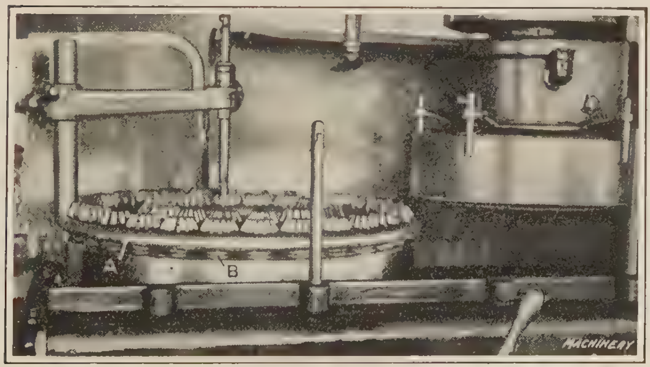
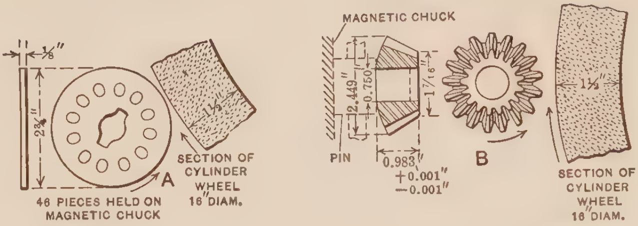


Fig. 24. Grinding Faces of Bevel Pinions on Vertical Surface Grinder

Fig. 23 shows how thirty-four levers for repeating rifles are held on the magnetic chuck at one time. No special fixtures are required, the pieces being simply located inside a retaining ring and held magnetically to the chuck.


1/8"
2 3/4"
A
46 PIECES HELD ON MAGNETIC CHUCK
1 1/2"
SECTION OF CYLINDER WHEEL 16" DIAM.
MAGNETIC CHUCK
2.449"
0.750"
1 7/16"
PIN
0.983"
+0.001"
−0.001"
B
1 1/2"
SECTION OF CYLINDER WHEEL 16" DIAM.

Machinery

A

Work: — Meat chopper disk, soft steel punching, not hardened.

Operation: — Surface grinding both sides from the rough with an American (silicate) corundum wheel; grain 24, grade 3/4; 16 inches diameter, 1 1/2-inch rim; speed, 1000 R.P.M. — 4190 feet surface speed; table speed, roughing, 13 R.P.M., finishing, 5 R.P.M.; down feed of wheel, 0.0014 inch per revolution of work-table; amount removed from each side, about 0.008 inch.

Remarks: — 46 of these parts are held at one time on Blanchard magnetic chuck located between two retaining rings; grinding time, 4 minutes, handling time, 4 minutes; limits, just clean up; production, 345 pieces per hour; machine used, Blanchard high-power vertical surface grinder.

B

Work: — Bevel pinion, 0.020 to 0.030 per cent carbon, open-hearth steel, carbonized and hardened.

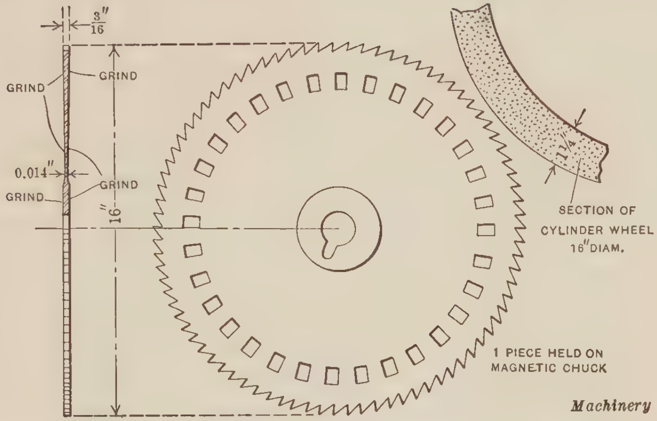
Operation: — Surface grinding one end from the rough with an American (silicate) corundum wheel; grain 30, grade 1 3/4-W; 16 inches diameter, 1 1/2-inch rim; speed, 950 R.P.M. — 3971 feet surface speed; table speed, 6 R.P.M.; down feed of wheel, 0.0005 inch per revolution of work-table; amount removed from end, 0.010 inch.

Remarks: — 44 of these parts are held at one time on a Blanchard magnetic chuck, being retained magnetically on pins held in a special fixture; handling time, 6 minutes; production, 200 pieces per hour; machine used, Blanchard high-power vertical surface grinder.

Fig. 25. (A) Soft Steel Disks and (B) Bevel Pinions ground on Vertical Machine

When parts such as are shown in Figs. 22 and 23 have been ground on one side, the chuck is moved to the end of the machine, the magnetism turned off, and both the work and the chuck rings removed, leaving the chuck face clear of everything except the water and chips. Cleaning may then be done with a rubber-edge scraper or squeegee such as is used for cleaning windows. By depressing the treadle at the front of the Blanchard machine, the operator can set the chuck in motion without leaving his position at the end of the machine, and, with the squeegee, can clean off the chuck face in a few seconds as it revolves. This cleaning is sufficient for ordinary work, as the squeegee removes the water and chips; when grinding very accurate work, a light rub with a cloth will give a dry, clean surface.

An interesting application of the vertical surface grinder to the grinding of bevel pinions is shown in Fig. 24. The part


3/16"
GRIND
GRIND
0.014"
GRIND
GRIND
16"
1¼"
SECTION OF CYLINDER WHEEL 16" DIAM.
1 PIECE HELD ON MAGNETIC CHUCK
Machinery

Work: — 16-inch (Higley type) metal-cutting saw, high-speed steel, hardened.

Operation: — Surface grinding both sides from the rough with a Norton (silicate) alundum wheel; grain 38–24, grade H; 16 inches diameter, 1¼-inch rim; speed, 1000 R.P.M. — 4190 feet surface speed; table speed, roughing, 8½ R.P.M., finishing, 5½ R.P.M.; down feed of wheel, 0.0016 inch per revolution of table; amount removed from each side, 0.015 inch; four operations — two for flat and two for concave grinding.

Remarks: — One of these parts held at one time on Blanchard magnetic chuck; grinding time, 8 minutes; handling time, 3 minutes; limits, plus or minus 0.002 inch; production, 6 per hour; machine used, Blanchard high-power vertical surface grinder.

Fig. 26. Grinding Sides of Metal Cutting Saw

to be ground, as shown at *B* in Fig. 25, is the front face, which measures about $1\frac{7}{16}$ inch in diameter. The fixture used consists of a ring *A* (Fig. 28) in which forty-four steel pins *B* are inserted. The upper ends of these steel pins are turned to fit the holes in the pinions, and the latter rest on top of ring *A*. The magnetic force holds the pinions down against the top surface of ring *A*, and, at the same time, prevents them from turning on the pins *B*. In this way, the pieces are held very effectively and the grinding can be done rapidly.

The cutting-off saw shown in Fig. 26 is an example of work for which the surface grinder of the rotary type is particularly adapted. This saw is ground all over, and, in addition, is made concave nearly to the center hole, to provide clearance. The flat surface of the saw is ground first on both sides; then the machine is adjusted so as to set the spindle off the desired angle to give the required concavity.

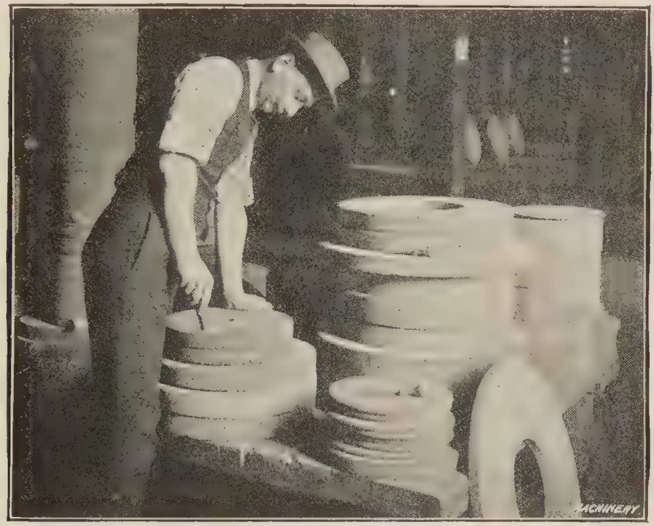
CHAPTER VI

GRINDING WHEEL ABRASIVES AND BONDING PROCESSES

The modern grinding wheel, when properly selected for the work upon which it is used, is very efficient, especially for the finishing of accurate work. The developments made in the manufacture of grinding wheels within the past few years have greatly assisted in placing the grinding machine in a class with other highly productive tools and have made possible great decreases in manufacturing costs. A grinding wheel may be compared to a milling cutter having an infinitely greater number of teeth or cutting points. For instance, on an average wheel 24 inches in diameter and 4 inches wide, approximately, 1,086,171,000 cutting points come into contact with the work each minute. The teeth or points that do the cutting are called "grains," whereas, the material used for holding the grains in the form of a wheel is called the "bond."

Grade of a Grinding Wheel. — The term "grade" as applied to a grinding wheel, refers to the tenacity with which the bond holds the cutting points or abrasive grains in place and does not refer to the hardness of the abrasive. A wheel from which the abrasive grains can easily be dislodged is called "soft" or of soft grade, whereas, one which holds the grains more securely is called a "hard wheel." By varying the amount and composition of the bond, wheels of different grades are obtained. Also the hardness of the wheel is, to a certain extent, governed by the size of the grains; for instance, if two wheels have the same bond, the one composed of the finer grains of abrasive is the harder. In other words, a 120-grain wheel would be harder than a 24-grain wheel of the same bond. The combination of different size grains also has a certain effect on the hardness of the wheel.

Grinding Wheel Grade Marks. — The grade of a grinding wheel is designated either by letters of the alphabet or numbers, or a combination of both, as will be seen by referring to the accompanying tables. According to the system employed by some manufacturers, the letter *M* represents a medium grade, and the successive order of letters or numbers preceding and following *M* denote softer or harder wheels. A standard system of grading has not been adopted by the various manufacturers. The tables referred to give lists of grading letters and numbers used by the principal grinding wheel manufacturers, and, in this connection, it should be clearly understood that these should not be used on a comparative basis. In the first place, the present method of grading wheels is not a mechanical test but is done by hand, as shown in the accompanying illustration, and requires considerable skill and experience. The tool used has a ball-shaped handle and a blade which is beveled on the end like a cold chisel. When making the test, the beveled end of this tool is simply pressed into the side of the wheel and is then turned or twisted. The resistance to this twisting action indicates, to the experienced man, the grade of the wheel. The necessary delicate sense of touch is soon lost even by an expert who discontinues the work for a short time.



Method of Determining Grade of Grinding Wheel

Grading Systems used by Grinding Wheel Manufacturers to Indicate Hardness of Bond in Grinding Wheels * — 1

Grade	Grinding Wheel Manufacturers										
	Abrasive Material Co.		American Emery Wheel Works			Carborundum Co.		Cortland Corundum Wheel Co.		Detroit Grinding Wheel Co.	
	Grade Letters and Numbers for Different Bonding Processes										
	Vit. and Sil.	Elast.	Vit.	Sil.	Elast.	Vit. and Sil.	Elast.	Vit. and Sil.	Elast.	Vit. and Sil.	Elast.
Extra Soft	G	¾ E	..	..	....	Z	..	D	D	C	..
	..	....	..	..	....	Y	..	E	E	D	½
	..	....	..	..	....	X	..	F	F	..	..
Very Soft	H	1 E	G	½	½ E	W	11	..	..	..	..
	I	....	H	¾	¾ E	V	10	..	..	E	¾
	..	....	I	1	1 E	U	..	..	..	F	..
Soft	J	....	J	1½	1½ E	T	9	G	G	G	..
	K	1½ E	K	2	2 E	S	8	H	H	H	1
	..	....	L	2½	2½ E	R	..	I	I	..	..
Medium Soft	..	....	..	..	....	P	7	J	J	I	..
	L	2½ E	..	..	....	O	6	K	K	K	1½
	..	....	..	..	....	N	5	L	L	..	..
Medium	M	3½ E	M	3	3 E	M	..	M	M	..	..
	..	....	N	3½	3½ E	L	4	N	N	L	2
	..	4 E	O	4	4 E	K	3	O	O	M	..
	..	....	..	..	....	J	..	..	..	..	..
Medium Hard	N	5 E	P	4½	4½ E	I	..	P	P	N	..
	O	6 E	Q	5	5 E	Ix	2	Q	Q	P	2½
	P	7 E	R	6	6 E	H	1	R	R	..	..
	..	....	..	..	....	Hx	..	..	..	..	..
Hard	Q	....	..	..	....	G	½	S	S	Q	3
	R	....	..	..	....	Gx	..	T	T	R	4
	..	....	..	..	....	F	..	U	U	..	..
	..	....	..	..	....	E	..	..	..	..	..
Very Hard	S	....	S	7	7 E	D	..	..	..	T	5
	T	....	T	..	....	....	..	..	..	U	6
	U	....	U	..	....	....	..	..	..	..	..
Extremely Hard	V	....	V	..	....	....	..	V	V	..	..
Special Extra Hard	Z	....	..	..	....	....	..	..	..	..	..

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* The grades listed by various manufacturers should not be used on a comparative basis, because the terms "soft," "medium," "hard," etc., and the corresponding grade letters or numbers do not always indicate the same degree of hardness.

Grading Systems used by Grinding Wheel Manufacturers to Indicate Hardness of Bond in Grinding Wheels* — 2

Grade	Grinding Wheel Manufacturers									
	Norton Co.		Safety Emery Wheel Co.		Sterling Grinding Wheel Co.		Vitrified Wheel Co.		Waltham Emery Wheel Co.	
	Grade Letters and Numbers for Different Bonding Processes									
	Vit. and Sil.	Elast.	Vit.	Sil.	Vit. and Sil.	Elast.	Vit. and Sil.	Elast.	Vit. and Sil.	Elast.
Extra Soft	..	...	C	6	1	1	....	....	..	.....
	..	...	C ½	..	1¼	1¼	....	....	..	.....
Very Soft	..	...	H	5½	1½	..	....	....	..	.....
	..	...	H ½	5	1¾	..	....	....	..	.....
Soft	E	1	A	4½	2	2	C	½ E	1½	1½ R
	F	1½	A ¼	..	2¼	2¼	C 1	1 E	1¾	......
	G	...	A ½	..	..	2½	C 2	1½ E	2	......
	H	...	A ¾	..	..	2¾	....	....	..	......
Medium Soft	I	2	M	4	2½	..	C 3	2 E	2¼	2 R
	J	2½	M ¼	..	..	..	D	2½ E	2½	......
	K	...	M ½	..	..	..	D 1	3 E	2¾	......
	L	...	M ¾	..	2¾	..	D 2	....	3	......
Medium	M	3	P	3½	3	3	D 3	3½ E	3¼	2½R
	N	4	P ¼	..	3¼	3¼	E	4 E	3½	......
	O	...	P ½	..	..	..	E 1	4½ E	3¾	......
	P	...	P ¾	..	..	..	E 2	....	4	......
Medium Hard	Q	5	1	3	3½	..	E 3	5 E	4¼	2¾ R
	R	...	1¼	..	..	..	F	5½ E	4½	......
	S	...	1½	..	..	..	F 1	....	4¾	......
	T	...	1¾	..	3¾	..	....	....	5	......
Hard	U	V 6	O	2½	4	3½	F 2	6 E	5½	3 R
	V	V 7	O ¼	2	..	3¾	F 3	6½ E	..	......
	W	...	O ½	..	..	..	....	....	..	......
	X	...	O ¾	..	4¼	..	....	....	..	......
Very Hard	..	...	N	1½	4½	4	G	....	..	3¼ R
	..	...	N ¼	..	..	4¼	....	....	..	......
	..	...	N ½	..	..	4½	....	....	..	......
	..	...	N ¾	..	4¾	4¾	....	....	..	......
Extremely Hard	Y	...	E	1	5	5	....	....	6	......
	Z	...	E ¼	..	5¼	5¼	....	....	..	......
	..	...	E ½	..	5½	5½	....	....	..	......
	..	...	E ¾	..	5¾	5¾	....	....	..	......
Special Extra Hard	..	...	D	..	6	6	....	....	..	4 R

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* The grades listed by various manufacturers should not be used on a comparative basis, because the terms "soft," "medium," "hard," etc., and the corresponding grade letters or numbers do not always indicate the same degree of hardness.

Considering the method used in testing and the human element which enters into it, it is not surprising to find that the grade letters or numbers adopted by different manufacturers cannot be used interchangeably. Careful comparison of the grades of the Norton Co. and the American Emery Wheel Works has shown that a grade "L" American wheel closely agrees with a Norton "L" wheel as regards hardness, but, the Norton grade "L" is listed as fourth in medium soft, whereas the American "L" wheel is graded as third in the "soft" list (see tables).

Grain of a Grinding Wheel. — The grain or coarseness of a wheel is designated by numbers which indicate the number of meshes to the linear inch through which the kernels of abrasive will pass. For instance, a 36 grain means that the abrasive will pass through a sieve having 36 meshes to the linear inch. The grains commonly used for plain cylindrical grinding vary from 24 to 60. There are two kinds of grains — straight and combination. In a "straight-grain wheel," all the particles of abrasive used are of about the same size, whereas, in a combination grain wheel, the particles of abrasives used are of different sizes. The exact combination of grains in a wheel is not specified by the wheel manufacturer. It requires considerable experimenting to determine the correct sizes and proportions of abrasive grains for a combination wheel, and some manufacturers use special numbers not representing the grain sizes, whereas others give numbers which indicate the size of the coarsest grains in the wheel. A correct combination of grains cuts fast and leaves a good finish on the work; moreover, a combination wheel will generally remain in a good cutting condition longer than a straight-grain wheel.

Abrasives for Grinding Wheels. — The abrasives used in the manufacture of grinding wheels are both natural and artificial. The chief natural abrasives are emery and corundum. Those artificially produced are adamite, alundum, aloxite, boro-carbone, carborundum, carbolite, crystolon, etc. Of the natural abrasives, corundum is the most widely used; it contains a much larger percentage of crystalline alumina than emery, this being the element in both abrasives that does the cutting.

Emery is very tough, but contains iron and other non-cutting elements, and is little used in wheels used on automatic grinding machines. With the exception of corundum, the greater percentage of abrasives used in grinding wheels are produced artificially in the electric furnace from bauxite and carbide of silicon. A number of the natural and artificial abrasives, designated by various trade names, together with their chief constituents and methods of manufacture will be given.

Adamite. — An artificial abrasive produced in Austria and used by the Detroit Grinding Wheel Co. The chief constituent is aluminum oxide which is mixed with certain ingredients to remove the impurities and is fused at a high temperature in the electric furnace. This abrasive is used in wheels for grinding materials of high tensile strength, such as soft and hardened steel, etc.

Alundum. — An artificial abrasive used by the Norton Co. It is made by fusing the mineral bauxite in the intense heat of the electric arc furnace. Bauxite is a soft earth resembling light yellow clay, and, chemically, is the purest form of aluminum oxide found in nature. The mineral bauxite derives its name from the ruined city and castle of Les Baux, in the southern part of France, where it was originally discovered. Large quantities of this mineral are now mined in Georgia, Alabama, and Arkansas. It is found in pockets and is mined in open cuts, then carefully washed, dried, and shipped to the plant where it is purified, and, subsequently, fused in the electric furnace. Alundum is used in wheels for grinding materials of high tensile strength. A special temper or "white alundum" is used by the Norton Co. in the manufacture of wheels for form grinding and similar operations. This is designated as No. 38 to distinguish it from the regular alundum.

Alowalt. — A trade name given to an abrasive used by the Waltham Emery Wheel Co. It is the product of the electric furnace and is made from aluminum oxide in practically the same manner as aloxite.

Aloxite. — An artificial abrasive manufactured by the Carborundum Co. It is made from crystalline aluminum oxide and is produced by fusing the mineral bauxite in the electric arc furnace. Bauxite is received from the mine in small lumps, and, after crushing, is calcined in rotary kilns to remove the moisture and volatile matter. It is then mixed with a certain percentage of coke, after which it is placed in the electric furnace. The furnace consists of a crucible-shaped steel receptacle which is lined with carbon and is movably mounted. The top is open and two vertical carbon electrodes extend down into the charge which is fused by the arc formed between the electrodes. The charge of bauxite is fed into the furnace from time to time until an ingot has been formed weighing several tons. The current is then shut off and the mass allowed to cool slowly. The ingot is then removed, crushed, and graded. Aloxite is used for grinding materials of high tensile strength.

Boro-carbone. — The trade name for an abrasive used by the Abrasive Material Co. It is a product of the electric arc furnace, and is oxide of aluminum in crystalline formation produced by fusing bauxite at a temperature of about 3800 degrees F. The temper of boro-carbone is varied according to the kind of work on which it is to be used, and its physical formation is such that it presents sharp cutting points when fractured. It is used for grinding all classes of materials of high tensile strength.

Carbide of Silicon. — The name given an abrasive by the Abrasive Material Co. It is used in the manufacture of grinding wheels for materials of low tensile strength, such as cast iron, brass, etc. The chief constituents of this abrasive are coke and sand. The coke supplies the carbon, and the sand, the silicon. These two substances are volatilized in the electric furnace.

Carbo-alumina. — The name of an artificial abrasive used by the Detroit Grinding Wheel Co. in the manufacture of wheels for grinding materials of high tensile strength. It is produced from the mineral bauxite in a somewhat similar manner to alundum.

Carbolite. — The trade name of an abrasive used by the American Emery Wheel Works in the manufacture of wheels for grinding materials of relatively low tensile strength, such as cast iron, brass, aluminum, etc. Carbolite is another name for carbide of silicon in the crystalline form and is made from coke and sand which is volatilized in the electric furnace.

Carbolon. — Manufactured by the Exolon Co. and used by the Vitrified Wheel Co. in making wheels for grinding materials of low tensile strength. Pure silicon carbide is a hard crystalline material in which the individual crystals are arranged in comparatively thin transparent layers of a greenish hue. Commercially, silicon carbide may be of a greenish hue, black, or highly colored. The black variety frequently has extremely thin layers of impurities, such as metallic silicon, metallic iron, etc., deposited between the crystalline layers. Carbolon is produced from coke and sand in the electric furnace in a manner similar to carbolite. It has been found that an accurate control of temperature in the reaction zone of the furnace is of the utmost importance, and, also, that the slightest variation in the mixture of raw materials produces a marked effect on the nature of the resultant crystalline mass.

Carborundum. — An artificial abrasive manufactured by the Carborundum Co. It is a chemical combination of carbon and silicon. The principal materials used in the manufacture of carborundum are coke and sand. The coke is used to supply the carbon, and the sand, the silicon. These two substances are raised to a temperature of about 7000 degrees F. All the impurities and other substances in the coke and sand, other than carbon and silicon, are driven off in gaseous form, and these two elements unite, forming the abrasive known as carborundum.

Carbowalt. — The name of an abrasive used by the Waltham Emery Wheel Co. It is manufactured from coke and sand in a somewhat similar manner to carborundum.

Corex. — An abrasive used by the Safety Emery Wheel Co. in the manufacture of wheels for grinding cast iron, unannealed malleable iron, brass, bronze, etc. It is produced from coke and sand in the electric furnace.

Corowalt. — A special temper corundum abrasive used in manufacture of grinding wheels by the Waltham Emery Wheel

Co. It is especially useful for the grinding of hardened low or high carbon steel. It is produced in the electric furnace in a manner similar to alundum.

Corundum. — This is the purest of natural abrasives and is a mineral composed of native alumina, which is noted for its hardness. This mineral was first found in India, in the eighteenth century, and derives its name from a native Indian name, Kurundam. The finely colored transparent varieties of this abrasive include such gem stones as ruby and sapphire, while the impure granular and massive forms are known as emery. Next to the diamond, corundum is the hardest known mineral. Large deposits of this mineral are found in Georgia, North Carolina, and also in Ontario, Canada. Corundum is produced artificially, although it is artificial only in the sense that it is crystallized by means of the electric arc furnace instead of by nature. Chemically, natural and artificial corundum are alike, both being composed of aluminum oxide in the crystalline form. A special grade of artificial corundum made by the American Emery Wheel Works, is known as No. 58, to distinguish it from the natural corundum. Artificial corundum was first made by Moissan, in Paris, in the electric furnace. The original process was improved by Werlem and patented in France. By these improvements, the impurities in the natural alumina were removed in the crystallizing process, so that practically pure crystalline alumina was the result. Wheels made from artificial corundum are designated by some number to distinguish them from wheels made from natural corundum. For instance, for the grinding of certain materials, such as steel, etc., if a 58–30 wheel were tested, the No. 58 refers to the artificial corundum.

Crystolon. — An artificial abrasive produced by the Norton Co., the chief constituents of which are carbon and silicon. Crystolon is made from coke, sand, sawdust, and salt. Coke is used to furnish the carbon element; the silicon comes from a pure silica sand which is secured in Illinois. Crystolon is a very hard, brittle abrasive and ranks next to the diamond in hardness. The elements, previously mentioned, are fused in an electric furnace at a temperature varying between 3500 and 4500 degrees F., the sand and coke combining to form carbide of silicon. This abrasive is used in the manufacture of wheels for grinding cast iron, brass, bronze, etc.

Emery. — In the early days of the grinding industry, practically all grinding wheels were made of emery, but other materials possessing superior cutting qualities are now largely employed in the grinding of metals, as well as for many other purposes. Emery, however, is a very tough abrasive and is unexcelled for some grinding operations. For example, it is effective when a very fine finish is required or for making very hard, fine wheels, such as are required for ball grinding. Emery is obtained from Naxos (an island in the Ægean Sea); from the vicinity of Smyrna, in Turkey; and from Chester, Massachusetts. The value of emery as an abrasive depends upon the percentage of crystalline aluminum oxide which it contains, as this is the only element in emery that is hard enough to cut metals effectively. While emery is a tough abrasive, it contains quite a large percentage of non-cutting elements composed of amorphous alumina, silica, iron oxide, and other metallic oxides, and is used comparatively little in machine grinding. Analyses of emery obtained from the different localities mentioned in the foregoing showed the following percentages of crystalline alumina: Naxos emery, 63 per cent; Turkish emery, 57 per cent; Chester emery, 55 per cent.

Oxaluma. — The trade name for an aluminum oxide abrasive used by the Cortland Corundum Wheel Co. in wheels for grinding materials of high tensile strength, such as soft or hardened steel, etc.

Rex. — The trade name for an aluminum oxide abrasive used by the Safety Emery Wheel Co. in wheels for grinding either soft or hardened steel. This abrasive is the product of the electric furnace, the process of manufacture being similar to that of alundum.

Bonding Processes. — By the use of different abrasives, grinding wheels can be produced which are adapted to many different purposes. The important properties of an abrasive are hardness, toughness, absence of impurities, uniformity, and fracture or sharpness. Inasmuch as these qualities vary, to some extent, in different abrasives, grinding wheels may be produced which possess varying characteristics, and, therefore, are effective in grinding not only metals of different composition but various other materials. The nature or characteristics of a grinding wheel can also be changed by using different bonds, the bond being the substance which holds the abrasive grains together in the form of a wheel. The three most important bonding processes are known as the vitrified, silicate, and elastic processes, and these names are applied to the wheels. For instance, a wheel made by the vitrified process is commonly referred to as a vitrified wheel, etc. Among other processes, which are occasionally employed, may be mentioned the vulcanite process, the celluloid process, and the oil process.

The first abrasive wheels known were natural stones, but the uses of these were greatly limited because they did not possess the required physical properties for the efficient cutting of metals. Subsequently, artificial abrasive wheels for grinding metals were bonded with hydraulic cement, which did not prove very satisfactory. Attempts were then made to use organic substances which melt when heated and become hard when cold. The shellac-, resin-, sulphur-, and rubber-bonded wheels were then tried, and, of these, shellac and rubber were successful to a certain degree. The next advance was to use silicate of soda and the vitrified or fused clay processes. These two processes are largely used today, the vitrified being used chiefly in the manufacture of wheels for use on automatic grinding machines.

Vitrified Process. — As vitrified grinding wheels are the most common, especially in connection with machine shop practice, the bonding of wheels by this process, as practiced at the plant of the Carborundum Co., will be described somewhat in detail. The bond of a vitrified wheel is composed of suitable clays and fluxes which are mixed with the proper abrasives. By varying the amount and composition of the bond, wheels of different grade are obtained. The base of all bonds for vitrified wheels is felspar or a fusible clay to which is added a refractory clay to decrease the fusibility of the bond. As the possible combinations of clays that may be used for bonding are almost endless, this is a branch of wheel manufacture that requires a great deal of experience.

The clays to be used are first dried, to eliminate all moisture, so that they can be proportioned by weight without the necessity of considering the weight of the moisture. Obviously, if there were an unknown amount of moisture in the different clays, it would be impossible to determine the relative weights with accuracy. The bond, after being pulverized and screened to remove lumps, is mixed with the abrasive grains in power mixing kettles having rotating paddles. After the mixture of bond and abrasive is placed in the kettle, water is added and the mixing process begins. It is very important that the correct amount of water be added, the amount depending upon the coarseness of the abrasive and the composition of the bond. The coarser the grain, the less water is used. If there is too much water in the mixture, the grains and bond separate, and the former, being heavier, sink to the bottom. An excessive amount of water also makes the wheels too compact, whereas, if the mixture is too dry, they will be too coarse. The mixing requires several hours and depends upon the coarseness of the abrasive and the kind of wheel for which the mixture is intended.

Molding Vitrified Wheels. — When the material for vitrified wheels is mixed by the wet process in power-driven kettles, as described in the foregoing, the mixture, which has the consistency of thick paint, is transferred from the mixing kettle to a mold; when the mold is full, the mixture is carefully worked to remove all air bubbles and insure a solid wheel. This operation requires considerable time when molding wheels which must be absolutely free from air bubbles, such as those used for grinding glass, etc. The molds are then partially air dried in an open room to prevent formation of cracks. This preliminary drying is followed by a more complete drying in a heated room. When the molded wheels are hard enough to be handled, they are ready to be turned to shape preparatory to burning in the kiln. The wheels are, of course, molded large to allow for turning and also to compensate for shrinkage in drying.

Truing Molded Wheels. — The rough molded wheel is trued and turned to the required form on a potter's wheel. This is a very simple device which consists principally of a revolving table and a horizontal cross-rail along which the tool-slide is fed by hand. The wheel to be trued is not held in any way but is simply placed on the center of the table which is made of plaster of Paris. The tool used for turning plain surfaces is a piece of flat, unhardened steel. This tool can be fed either vertically or horizontally, and scales on the machine enable the operator to turn to the required dimension without taking any measurements.

The wheel is not reduced to the size finally required but an allowance is made for shrinkage in the kiln and also to provide material for a final truing operation after burning. This allowance depends upon the size and grain of the wheel. A coarse wheel requires a greater allowance than a fine one, other conditions being equal. In the operation of the potter's wheel, hand tools are used, to a certain extent, particularly in the formation of special shapes.

Burning Vitrified Wheels. — The next process in connection with vitrified grinding wheel manufacture is the burning of the wheels, in order to partially melt the bond and form a solid but porous wheel. Much skill and care is required to burn wheels successfully, as the temperature must be very accurately controlled for long periods. The wheels to be burned are stacked in a large brick kiln and are protected against the direct action of the flames and gases by packing them in fireclay saggers. When the kiln is full, the door is closed and luted with fireclay, and the burning begins. This continues, without interruption, for a period of from three to five days; the furnace is then allowed to cool slowly for a week.

Molding by Hydraulic Pressure. — When very hard, close, vitrified wheels are required, they are molded under the hydraulic press. Very strong molds must be used, as the pressures are enormous. For example, a 36-inch wheel would require a pressure of about 1000 tons. The bond and grain for pressed wheels are first mixed dry in a tumbling barrel, after which water is added until the proper consistency is obtained; the mixture is then spread evenly in the steel molds and pressed. The wheels are at once removed from the molds, dried, and "fired" in the same manner as other vitrified wheels.

The Tamped Process. — Still another method of molding vitrified wheels is known as the "tamped" process. The abrasive and clay for the bond are mixed together in a comparatively dry condition, and this mixture is then rammed into molds of the required size. After molded wheels have dried, they are burned in a kiln, the same as the wet-mixed wheels. The tamped process is used principally for making small wheels.

Qualities of Vitrified Wheels. — A vitrified grinding wheel has the following qualities: It is very porous and, therefore, free-cutting; it is not affected by water, oils, acids, temperature, or climatic conditions; the bond is hard and practically an abrasive in itself; the wet-mixed vitrified process insures uniformity in the wheel, there being no hard or soft spots; the high temperature required for burning vitrified wheels burns out impurities, leaving nothing but the abrasive and its bond.

Objections to Vitrified Process. — The disadvantages of the vitrified process are that the process is slow; large wheels are liable to be cracked in the kiln; it is impracticable to produce wheels larger than about 34 inches in diameter, and many manufacturers will not make wheels larger than 24 or 30 inches; the burning process is difficult to control perfectly, so that a given lot of wheels are liable to be somewhat "off grade"; the intense heat of burning slightly weakens the abrasive grains.

Vitrified wheels are extensively used for cylindrical grinding, for surface grinding when a disk form of wheel is used, for internal grinding, cutter grinding, and for many other purposes. They can readily be distinguished from other wheels by the reddish or reddish-brown color and the clear ringing sound produced when they are tapped.

Silicate Bonding Process. — Silicate wheels derive their name from the fact that silicate of soda or water glass is the principal ingredient used in the bond. These wheels are also sometimes referred to as semi-vitrified wheels. In brief, the process consists of thoroughly mixing silicate of soda and the abrasive grains in special mixing machines, and then ramming this mixture into molds. The wheels are then dried and afterwards baked in special ovens from which all fire gases are carefully excluded. As the result of this baking, the bond hardens or sets. Some shapes of silicate wheels are molded by hydraulic pressure, as, for example, "dish wheels" and those which must be exceptionally hard. It is important that the bond and abrasive be so mixed as to secure the proper consistency or "stickiness" and granular condition that is required for tamping the wheel to a uniform density, so that the wheel itself will not only be uniform throughout but uniform as compared with other wheels of the same kind. To appreciate the importance of preparing the material for tamping, one needs only to make a few wheels to learn that large differences in grade may be produced by the manner in which the bond and abrasive mixture packs into the mold. The tamping of silicate wheels requires considerable experience, in order to secure uniformity of grade and a well-balanced wheel. When the wheels are being heated, the time and temperature factors are also important, because over-burning does as much damage as under-burning, and the allowable limits of variation are small. After the wheels are removed from the oven, they are trued, graded, balanced, bushed for the grinding spindle, and inspected.

While silicate of soda is the principal ingredient of the bond, other substances have to be added, and, as there is quite a variety, silicate wheels can be modified to suit the conditions. In contrast with vitrified wheels, there are not many silicate wheels used, but, for certain purposes, they possess advantages. Ordinarily, they cut smoothly and with comparatively little heat, and for grinding operations requiring the lowest wheel wear compatible with cool cutting, silicate wheels are often used. Their grade is also dependable and much larger wheels can be made by this bonding process than by the vitrified process. Vitrified wheels are rarely made larger than from 30 to 34 inches, whereas, silicate wheels up to 60 inches in diameter are produced. Silicate wheels of the harder grades, however, are not as satisfactory as vitrified wheels, because they are of closer texture and do not cut as freely.

The advantages of the silicate bonding process may be summarized as follows: It is rapid and special wheels may be made in a few days; it is dependable, as the baking process is easily controlled; excessive heat is not required, so that the original strength of the abrasive grains is not impaired. For wet grinding, the soda in the bond acts as a lubricant, causing the wheel to cut smoothly and with comparatively little heat. Wheels of any size up to 60 inches or even larger may be made. Silicate wheels may be molded on iron centers or backs, which is not the case with vitrified wheels, since the burning temperature would melt the iron. As to the disadvantages, the harder grades of silicate wheels do not cut as freely as vitrified wheels of the same grade and wheels requiring extraordinary hardness and durability cannot be made by the silicate process.

Some of the grinding operations for which silicate wheels have been found to be especially adapted are as follows: For grinding high-speed steel machine shop tools, such as reamers, milling cutters, etc.; for hand grinding lathe and planer tools; for surface grinding with machines of the vertical ring-wheel type; and, for operations requiring dish-shaped wheels and cool cutting. These wheels are unequal for wet grinding on hardened steel and for wet tool grinding. They are easily recognized by their light gray color.

Elastic Wheels. — Very fine grinding wheels are made by the elastic process. Shellac is the principal ingredient in the bond and the wheels made by this process are strong and have considerable elasticity, so that very thin wheels can be used safely. Wheels $\frac{1}{32}$ inch thick are manufactured. After the bond and abrasive have been prepared, its consistency is such that if thin wheels are to be made, the mixture may be rolled into shallow molds; thicker wheels are formed by ramming into molds, the same as silicate wheels, or by means of hydraulic pressure, the method depending upon the size. The molded wheels are baked at low temperature, to set the shellac.

The advantages of the process are that very thin wheels, of sufficient strength to be used safely, may be produced. Their elasticity tends to smooth cutting, so that a fine finish may be obtained whether they are used wet or dry. The process is rapid and easily controlled, and elastic wheels may be molded on iron centers or backs. Elastic wheels are less open and porous than vitrified wheels, however, and will not withstand much heat; they are nearly black in color.

Thin elastic wheels are used for slotting and for cutting off stock such as tubing, pipes, wire, thin sheets of tin or brass, and other materials, especially when the parts are difficult to hold for cutting with regular tools. Thicker elastic wheels are employed for saw-gumming, grinding the teeth of gears, sharpening woodworking tools, etc. They are also used for cutlery work and roll grinding, where a very smooth polished surface is desired. Elastic wheels may safely be run in water but should not be used in oil or caustic soda, because the oil will soften the bonding material, causing the wheel to quickly wear out, whereas caustic soda will disintegrate the wheel structure. For cutting-off work, a wheel speed varying from 9000 to 11,000 feet per minute has been found to be the most efficient. For general operations, aside from cutting off, a speed of from 5000 to 6000 feet per minute is recommended. These thin cutting-off wheels will do work which cannot be done with an edged cutting-off tool, as, for example, the cutting off of unannealed high-speed steel stock. The machines used for this work are very simple. When cutting off small light pieces, the wheel rotates in a fixed position and the work is moved against it, whereas, for cutting long and wieldy parts, the work is held stationary and the wheel is given the feeding movement. These machines will cut off steel, iron, bronze, brass, copper, tubing, pipe, and other metal parts up to about 3 inches in diameter.

Vulcanite, Celluloid, and Oil Processes. — In the vulcanite process, the abrasive grains are bonded by the use of vulcanized rubber. Very hard, tough, thin wheels can be produced in this way, but they are expensive. The abrasive is rolled into the prepared rubber, and this mass, while warm, is molded into wheels which are heated while under pressure, to vulcanize the rubber. Vulcanite wheels, like those of the elastic type, are made very thin and are adapted for cutting off tubing, wire, thin sheets of steel or brass, and parts which are difficult to hold for cutting by regular tools. For general cutting-off operations, when the speed of cutting is not an important factor, vulcanite wheels are generally considered preferable to the elastic wheels. The latter, however, can be used to better advantage for cutting off tempered tool steel or alloy steel tools, when cool cutting is important, because of their softer grades and cooler grinding action.

While elastic and vulcanite wheels are used, to some extent, for operations other than slotting, grooving, nicking, and cutting off, they have been largely superseded by vitrified wheels. This is because the coarse structure of the vitrified bond gives a much freer and cooler cutting or grinding action and a proportionate increase of production. For some classes of work, however, the elastic and vulcanite wheels are unsurpassed. Vulcanite wheels can be safely run in water, and they are not injured by oil or caustic soda, as are the elastic wheels.

Wheels made by the celluloid process have a bond of celluloid, as the name implies. The abrasive grains are mixed with strap celluloid and this mixture is rolled into sheets from which the wheels are cut. After seasoning for several months, the wheels are ready to finish. Wheels bonded in this way are also comparatively high in price.

With the oil process, an oxidizing oil is mixed with the abrasive grains. After this mixture has thickened from exposure to the air, it is formed into wheels, by compressing it into molds by means of hydraulic presses. The molded wheels are then baked slowly at a low temperature. Oil wheels are similar in action to elastic wheels but less dependable as to grade and uniformity. The three processes referred to in the foregoing are only used to a limited extent.

CHAPTER VII

SELECTION OF WHEELS FOR GRINDING

WHEN selecting a grinding wheel, there are several factors which must be considered. The grade and grain depend largely upon the area of contact between the wheel and work, the kind of material to be ground, and its degree of hardness. A harder wheel should be used on soft machine steel than on hardened tool steel. The reason for this will, perhaps, be better understood if we think of a grinding wheel as a cutter having attached to its periphery an innumerable number of small teeth, for this is literally what the thousands of small grains of abrasive are. When the wheel is of the proper grade, these small teeth or cutting particles are held in place by the bond until they become too dull to cut effectively, when they are torn out of place by the increased friction. Obviously, these grains or cutters will become dulled sooner when grinding hard than when grinding soft steel; hence, as a general rule, the harder the material, the softer the wheel, and *vice versa,* although soft materials, such as brass, are ground with a soft wheel, which crumbles easily, thus preventing the wheel from becoming loaded or clogged with metal, as would be the case if a hard-bonded wheel were used.

When a hard wheel is used for grinding hard material, the grit becomes dulled, but it is not dislodged as rapidly as it should be, with the result that the periphery of the wheel is worn smooth or glazed, so that grinding is impossible without excessive wheel pressure. Any undue pressure tends to distort the work, and this tendency is still further increased by the excessive heat generated. If the surface of the wheel becomes "loaded" with chips and burns the work, even when plenty of water is used, it is too hard. When a wheel is used which is too soft, the wear is, of course, greatly increased, as the particles of grit are dislodged too rapidly, and, consequently, the wheel is always "sharp." This means that the abrasive has not done sufficient work to become even slightly dulled and the result is a rough surface on the work. In regard to selecting the proper grinding wheel, as a general rule, materials of high tensile strength, such as soft and hardened steel, etc., require a wheel made from an aluminum oxide abrasive, whereas, for grinding materials of low tensile strength, such as cast iron, brass, bronze, etc., a wheel made from a carbide of silicon abrasive should be used.

Effect of Arc of Contact. — The area of the surface which is in contact with the wheel should be considered when selecting the proper grade. For a given material, the wheel should be softer as the area increases. To illustrate, a wheel of grade *M* might be suitable for grinding cylindrical pieces 2 inches in diameter but not suitable for a diameter of 4 inches, because of the increased contact area, owing to the increase in diameter. This explains why softer wheels are required for surface grinding than for external cylindrical grinding operations.

For grinding small cylindrical work, as shown at *A*, Fig. 1, the conditions, so far as the arc of contact is concerned, are almost ideal because of the small arc of contact; the work and wheel may also be cooled easily; and, in addition, the dull abrasive grains readily fall out of the way and do not interfere with the grinding operations. An increase in the diameter of the work *b*, in relation to the wheel diameter, increases the arc of contact and may necessitate using a wheel of different grade. All other factors being equal, the larger the diameter of the work, the softer the wheel should be. On surface grinding with a disk wheel, as shown at *B*, the conditions are not quite so satisfactory because, in this case, a greater portion of the wheel surface comes into contact with the work. When a narrow wheel of this shape is used and is fed across the work *c* a certain distance for each traverse of the table, very little difficulty is encountered if water or other cooling lubricants can be used. When the grinding must be done dry, however, considerable trouble is sometimes experienced due to heating and warping, especially when the work is thin; therefore, wheels of a softer grade are used for grinding under the conditions shown at *B* than for grinding cylindrical parts as indicated at *A*.

For internal grinding, as shown at *C*, still more attention must be given to the grading of the wheel, because the arc of contact between the wheel and work *d* is much greater than in the other cases mentioned, and the difficulty of using a cooling lubricant is also increased. On small hole work, wheels are usually ordered of the same diameter as the hole, or slightly larger, and then are trued until they just enter the hole. In such a case, the arc of contact is greatly increased and the work and wheel tend to heat more rapidly; the difficulty of injecting a cooling lubricant into the hole is also increased. This makes

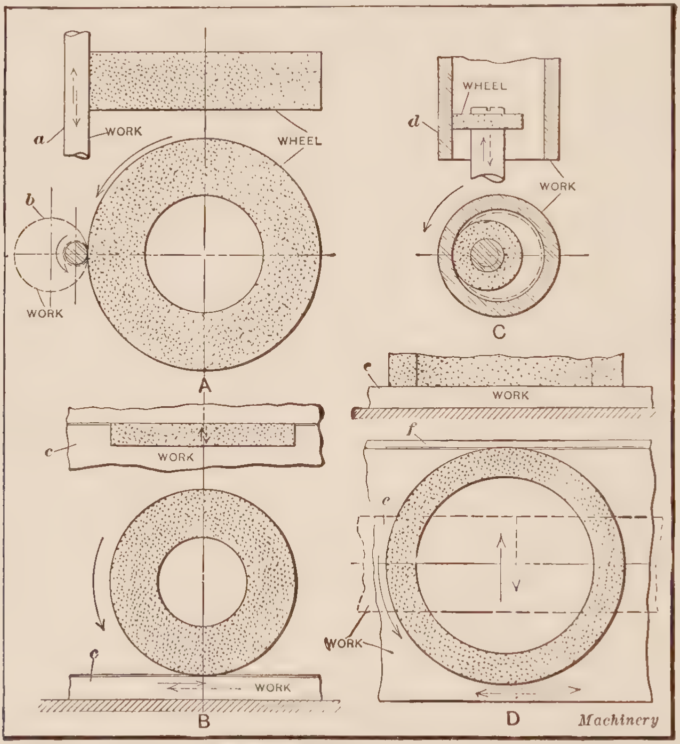


Fig. 1. Diagrams illustrating Variation in Arc of Contact between Wheel and Work for Different Grinding Operations

it necessary to use a much softer wheel than if the wheel were smaller in relation to the diameter of the hole.

The most severe condition under which a grinding wheel operates and one that requires the greatest attention in the selection of the proper grade and grain is that of surface grinding by the method illustrated at *D*. There are two conditions that must be taken into consideration. The first one is where the work *f* is wider than the diameter of the ring or cylinder wheel used. As the entire cutting face is in contact with the work, a wheel of extremely soft bond and coarse grain should be used to secure satisfactory results; otherwise, the work will be heated to such an extent that it will spring out of shape and accurate results are impossible. It is necessary also to have a copious supply of cooling liquid to reduce the heat.

The other condition is where the work *e* is less in width than the diameter of the wheel. In this case, the work has a tendency to tear the grains out of the bond; hence, a wheel of harder bond is required because of the shaving action of the edges of the work on the surface of the wheel. As the contact area is reduced, a wheel of finer grain may be used.

Determining Grain of Wheel. — The grain or degree of coarseness of a grinding wheel is another point to be considered when making a selection. Generally speaking, coarse wheels are better adapted to most work, because the larger grains permit deeper cuts to be taken. When a very fine finish is required, particularly on a number of duplicate pieces, fine wheels are often used for finishing, after the work has been ground close to the required size with a coarse wheel. It is not necessary, however, to use a fine wheel in order to obtain a surface that is smooth enough, for ordinary machine parts, as a wheel of comparatively coarse grain will produce a finish fine enough for most purposes, if the work speed is reduced somewhat and the wheel is trued with a rather dull diamond just before taking the finishing cut; in fact, very fine surfaces can be obtained with a comparatively coarse wheel of the proper grade and grain, provided there is the correct relation between the surface speeds of the wheel and work and the wheel is carefully

Table I. Grain and Grade of Grinding Wheels for Plain Cylindrical Grinding

Wheel M'n'f'r*	Abrasive (All Wheels Bonded by Vitrified Process)	0.20 to 0.50 per cent Carbon Steel (Soft)		0.20 to 0.50 per cent Carbon Steel (Hardened)		Chrome-nickel or Chrome-vanadium Steel (Heat-treated)	
		Grain	Grade	Grain	Grade	Grain	Grade
A	Boro-carbone....	24 to 46 Comb.	*L* to *M*	24 to 46 Comb.	*K*	24 to 46 Comb.	*M* to *N*
B	Corundum......	58–24. Comb.	*L* to *M*	46 to 60	*K*	58–24 Comb.	*L*
C	Aloxite..........	36	*M* to *O*	36	*P*	40	*J*
D	Oxaluma........	36	*M* to *N*	38 to 46	*K* to *L*	24 to 36	*M*
E	Corundum......	46	*M* to *N*	46	*O* to *P*	24 to 36	*M* to *O*
F	Alundum.......	38–36 Comb.	*L*	46	*K*	38–24 Comb.	*L*
G	Rex.............	30 to 36	*M* to *P*	30 to 36	*M* to *P*	24 to 36	*M* to *P*
H	Corundum......	20 to 36	2 to 2½	36	2	20 to 30	2½ to 3
I	Corundum......	24 to 36	D^2 to D^3	36 to 40	E^1 to E^2	24 to 30	D^3 to E^1
J	Alowalt	30 Comb.	3¼ to 3¾	....	....	30 Comb.	3¼ to 3¾
J	Corowalt	....	....	50	2¾	....	....

Wheel M'n'f'r*	Abrasive (Vitrified Bond except where marked under Grade)	Cast Iron		Cast Brass and Bronze		Cast Aluminum	
		Grain	Grade	Grain	Grade	Grain	Grade
A	Carbide of silicon	30 to 60	*K* to *M*	30 to 46	*L* to *N*	30 to 36	2 *E* to 3 *E*‡
B	Carbolite........	36 to 54	*K* to *M*	....	....	46 to 60	2 *E* to 2½ *E*‡
B	Corundum......	....	....	24	*M* to *N*	....	....
C	Carborundum...	24 to 60	*L* to *N*	24 to 36	*L* to *M*	16 to 24	2‡
D	Carborundum...	16 to 30	*L* to *M*	....	....	....	....
D	Oxaluma........	....	....	20 to 36	*M* to *O*	16 to 30	*N* to *R*
E	Carborundum...	16 to 36	*G* to *S*†	36 to 46	*N* to *P*†	20 to 36	*J* to *K*†
F	Crystolon.......	30	*J* to *K*	30	*K* to *L*	36	4‡
G	Corex...........	24 to 36	*M*½ to *P* ½	20 to 30	*P* ½ *I* ½	30 to 36	*M* ½ to *P* ½
H	Corundum......	20	2 to 3	30	3	30 to 36	3 to 3½
I	Carbolon........	24 to 46	D_2 to E_1	....	....	36	4½‡
I	Corundum......	....	....	24 to 30	E_3	....	....
J	Carbowalt	24 to 46	2¾ to 3½	30 to 46	2¾ to 3½	30 to 46	2½ to 3‡

* The letters in the first column represent the following wheel manufacturers: (*A*) Abrasive Material Co.; (*B*) American Emery Wheel Works; (*C*) Carborundum Co.; (*D*) Cortland Corundum Wheel Co.; (*E*) Detroit Grinding Wheel Co.; (*F*) Norton Co.; (*G*) Safety Emery Wheel Co.; (*H*) Sterling Grinding Wheel Co.; (*I*) Vitrified Wheel Co.; (*J*) Waltham Emery Wheel Co.

† Grinding wheel bonded by silicate process.

‡ Grinding wheel bonded by elastic process.

NOTE. The numbers 38 and 58 preceding, in some cases, the grain sizes, indicate a special manufacturing process for the abrasive listed.

trued with a diamond tool. When roughing cuts are being taken, the cutting particles are constantly worn away or dislodged, so that the face of the wheel is kept rough or "sharp" and the ground surface is also comparatively rough. After the wheel-face has been trued with a diamond, however, light finishing cuts, in conjunction with a reduced work speed, will give a finish which is smooth enough for all practical purposes, even though a fairly coarse wheel is used.

Incidentally, it is not always the highly polished surface which represents the most accurate work, because this finish is sometimes obtained at the expense of accuracy, by using hard wheels that require so much pressure to make them grind that the work is distorted. In order to secure accuracy, the wheel must cut freely and without perceptible pressure. Sometimes, a coarse wheel will not cut after a surface has been finished to a certain point, because the cutting particles wear off somewhat and the ends become too large and blunt to enter the smooth surface. If this occurs, the wheel should be trued with a diamond or be replaced with one of finer grain. When grinding brass or soft bronze, the grain of the wheel must be as fine as the finish desired; in other words, it is not practicable to use a coarse wheel for finishing these metals.

Wheels for Cylindrical Grinding. — While it is impossible to give definite information regarding the selection of grinding wheels, owing to the different factors which must be considered in each case, the wheels listed in the accompanying tables will enable one to obtain a general idea of the grades and grains that are commonly used for grinding different materials.

Table I gives a list of wheels recommended by various wheel manufacturers for grinding soft, hardened, and alloy steel, cast iron, brass, bronze, and aluminum and can be used as a basis in making the proper selection. By referring to this table, it will be noticed that for grinding cast iron, cast brass, bronze, and aluminum, in most cases, wheels made from carbide of silicon abrasives are recommended, although there are a few manufacturers who recommend aluminum-oxide abrasives for this work. It will also be noticed that the bonding processes recommended by the various wheel manufacturers differ to some extent.

For large-diameter cast-iron work, the Norton Co. recommends a wheel of grain 30, grade J, crystolon, and for small-diameter cast-iron work, a grain 30, grade K, crystolon. The wheel for large diameters is one grade softer than for comparatively small diameters. For bronze, a grain 30, grade K, crystolon wheel has been used to advantage. When grinding armatures or other parts where copper and wrought-iron pieces are arranged alternately, a Norton crystolon elastic wheel, grain 46, grade 2, has been used with success. For grinding chilled cast-iron rolls of large diameter, where it is desired to have a surface free from scratches, a crystolon wheel, grain 80, grade J has given good results. Of course, it will be understood that this information is intended only as a general guide.

There is such a large variety of alloys in use that it is difficult to specify any particular grain or grade of wheel that can be used satisfactorily on all of them. For instance, it is now necessary to distinguish between numerous kinds of brass of high and low zinc content, such as "red" and "yellow" brass, bronze, naval brass, and many others. The term "bronze" was formerly employed to indicate an alloy, the chief constituents of which were copper and tin (copper predominating), but in recent years many different alloys are referred to as bronzes. Commercial brass is generally understood to mean an alloy of two-thirds copper and one-third zinc, but this varies. The copper content may vary from 60 per cent to 80 per cent; the amount of copper and tin in bronze also varies considerably.

For nickel-bronze, a wheel made of crystolon, grain 24, grade Q gives good results. For bell metal, a wheel of the same material but of a little harder grade is recommended, such as grade R and grain 24 or 30. Comparatively thin wheels are often used for such metals and the work is ground by what is known as the "fixed-wheel" method. Careful experiments made in grinding brasses and bronzes with a crystolon wheel showed that a grain 30, grade P wheel gave the best results.

Wheels for Form Grinding. — In form grinding, the wheel is fed straight in on the work without being traversed, and, therefore, is required to take both a roughing and finishing cut. Usually, pieces that are form ground (crankshafts not being considered) are finished right from the rough-turning to the final grinding in one straight-in cut. It is not uncommon, therefore, to find that the wheels generally recommended for form grinding are of a combination grain. Table II gives the grain and grade of wheels for form grinding as recommended by various grinding wheel manufacturers. The conditions which govern the grain and grade of the wheel for form grinding are the face of the wheel in contact with the work, the rigidity of the machine in which the wheel is held, and the speed at which the work is rotated. For average work, a combination grain, grade M or N wheel is recommended. These grades of wheels have been found to give good results on from 0.20 to 0.50 carbon steel, not hardened, as well as chrome-nickel or chrome-vanadium steel, heat-treated.

Table II. Grain and Grade of Grinding Wheels for External Form Grinding

Wheel M'n'f'r*	Abrasive (Vitrified Bond except where Marked under Grade)	0.20 to 0.50 Per cent Carbon Steel (Soft)		0.20 to 0.50 Per cent Carbon Steel (Hardened)		Chrome-nickel or Chrome-vanadium Steel (Heat-treated)	
		Grain	Grade	Grain	Grade	Grain	Grade
A	Boro-carbone....	24 Comb.	*L* to *M*	24 Comb.	*J* to *K*	24 Comb.	*L* to *M*
B	Corundum......	58–24 Comb.	*L* to *M*	46 to 60	*K* to *L*	58–36 to 58–60	*J* to *L*
C	Aloxite..........	24 to 30	*J* to *K*	24 to 30	*M*	24 to 30	*J* to *K*
D	Oxaluma........	24 to 54	*L* to *M*	24 to 60	*K* to *L*	30 to 46	*K* to *M*
E	Carbo-alumina..	36 to 46	*M* to *P*†	36 to 46	*L* to *O*†	36 to 46	*M* to *O*†
F	Alundum.......	24 Comb. or 46	*L* to *N*	20 Comb. or 46	*L* to *N*	24 Comb. or 46	*J* to *M*
G	Rex............	24 to 60	*M* ½ to *P* ½	24 to 60	*M* to *P*	24 to 60	*M* to *P*
H	Corundum......	20 to 36	2 to 2½	20 to 30	2	16 to 20	3½
I	Corundum......	46	*E*	36 to 54	D_2	36 to 46	D_3 to *E*
J	Alowalt.........	46	3 to 3½	50	2¾ to 3¼	46 to 60	3 to 3½

* For list of wheel manufacturers which letters represent, see foot-note Table I.
† Grinding wheel bonded by silicate process.

NOTE. The number 58 preceding, in some cases, the grain sizes, indicates a special manufacturing process for the abrasive listed.

Wheels for Internal Grinding. — The selection of the proper grain and grade of wheel for internal grinding depends not only upon the kind of work and the work and wheel speeds, but also very largely upon the stiffness of the machine and the firmness with which the wheel-spindle is supported. Briefly summarized, some of the points to take into consideration are: Diameter of hole; speed of wheel-spindle; kind of work; whether the hole is plain or keyseated; nature of material; stiffness of machine; rigidity of wheel-spindle; and whether the cut is for roughing or finishing.

As regards the diameter of the hole, there are several points to consider. In the first place, where the hole is below $\frac{3}{4}$ or 1 inch in diameter, for economical reasons, it is necessary to have the wheel as large as possible; the wheel is usually ordered of the same diameter or larger than the hole to be ground and then is trued until it enters the hole. By using a wheel practically the same size as the hole, as shown at *A* in Fig. 2, the arc of contact of wheel and work is large, and, consequently, a much softer wheel must be used than if the wheel were small in relation to the diameter of the hole. Where the wheel is small, a harder bond and finer grain wheel can be used. The lower

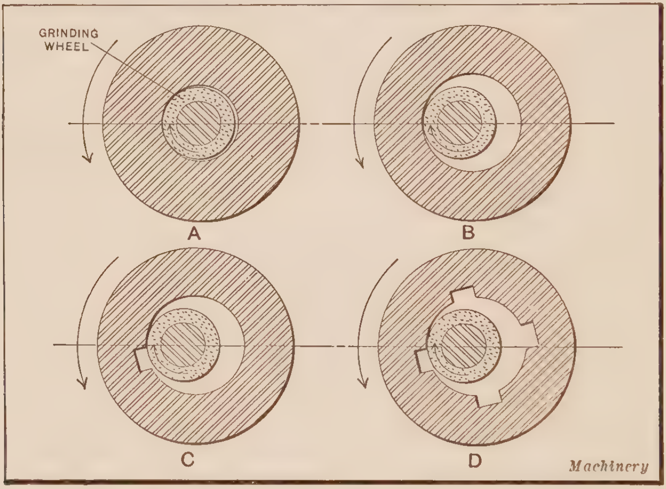


Fig. 2. Examples illustrating Points to Consider when Selecting Wheels for Internal Grinding

Table III. Grain and Grade of Grinding Wheels for Internal Grinding

Wheel M'n'f'r*	Abrasive (Vitrified Bond except where Marked under Grade)	0.20 to 0.50 Per cent Carbon Steel (Soft)		0.20 to 0.50 Per cent Carbon Steel (Hardened)		Chrome-nickel or Chrome-vanadium Steel (Heat-treated)	
		Grain	Grade	Grain	Grade	Grain	Grade
A	Boro-carbone......	46 to 60	*L* to *M*	46 to 60	*J* to *K*	46 to 60	*J* to *L*
B	Corundum........	36 to 46	*K* to *L*	46 to 60	*J* to *K*	58–46	*J* to *K*
C	Aloxite...........	50	*M* to *N*	60	*M* to *N*	50	*M* to *N*
D	Oxaluma..........	46 to 50	*J* to *K*	46 to 60	*J* to *K*	46 to 50	*K* to *L*
E	Carbo-alumina....	46	*L* to *N*†	60	*J* to *L*†	46	*I* to *K*†
F	Alundum.........	38–46	*J* to *M*	38–46	*J* to *L*	38–46	*J* to *K*
G	Rex..............	46	*M* to *P*	60	*M* to *P*	46	*M* to *P*
I	Corundum........	46	D_2 to D_3	60	D_2 to D_3	46	D_3
J	Alowalt...........	46 to 60	2½ to 3	46 to 60	2½ to 3	46 to 60	2½ to 3

Wheel M'n'f'r*	Abrasive (Vitrified Bond except where Marked under Grade)	Cast Iron		Cast Brass and Bronze		Cast Aluminum	
		Grain	Grade	Grain	Grade	Grain	Grade
A	Carbide of silicon.	46 to 60	*K* to *M*	46 to 60	*L* to *M*	46 to 60	2 *E* to 3 *E*‡
B	Carbolite..........	46 to 60	*J* to *L*	....	....	46 to 60	1½ *E* to 2 *E*‡
B	Carbolite or corundum.........	....	....	46 to 60	*K*	....	....
C	Carborundum.....	36 to 40	*P* to *S*	40 to 50	*M* to *P*	50	*P* to *R*
D	Carborundum.....	30 to 46	*K*	....	....	....	....
D	Oxaluma..........	....	....	46 to 60	*L* to *M*	36 to 54	*M* to *N*
E	Carborundum.....	36 to 46	*K* to *M*†	36 to 46	*J* to *L*†	24 to 36	*H* to *K*†
F	Crystolon.........	30 to 46	*I* to *L*	30 to 46	*K* to *M*	36	2 to 3‡
G	Corex.............	36 to 60	*M* to *M*¾	36 to 60	*M* to *M*½	36 to 60	*M* to *M*¾
I	Carbolon..........	36	D_2	....	....	46	4‡
I	Corundum........	....	....	46	D_3	....	....
J	Carbowalt	30 to 46	2 to 3	....	....	30 to 46	1¾ to 2‡
J	Alowalt...........	....	....	50	2½ to 2¾	....	....

* For list of grinding wheel manufacturers which letters represent, see foot-note, Table I.
† Grinding wheels bonded by silicate process.
‡ Grinding wheels bonded by elastic process.

NOTE. The numbers 38 and 58 preceding, in some cases, the grain sizes, indicate a special manufacturing process for the abrasive listed.

the wheel speed, the harder the bond should be, other conditions remaining the same.

When a hole is plain, as shown at *B*, Fig. 2, a softer wheel should be used than if the hole were keyseated, as shown at *C* and *D*. Slots or keyseats have a shaving action on the wheel-face and quickly tear out the grains; hence, for keyseated work, a harder wheel should be used than on plain hole work, and it should also have a wider face.

Table IV. Grain and Grade of Grinding Wheels for Surface Grinding — 1

Wheel M'n'f'r*	Abrasive (Vitrified Bond except where Marked under Grade)	0.20 to 0.50 Per cent Carbon Steel (Soft)		0.20 to 0.50 Per cent Carbon Steel (Hardened)		Chrome-nickel or Chrome-vanadium Steel (Heat-treated)	
		Grain	Grade	Grain	Grade	Grain	Grade
	Grinding Wheels of Disk Type						
A	Boro-carbone........	24 Comb.	*L* to *M*	24 Comb.	*J* to *K*	24 Comb.	*L* to *M*
B	Corundum..........	30 to 46	*J* to *K*	36 to 46	*I* to *J*	58-30 to 58-46	*I* to *J*
C	Aloxite..............	24	*N* to *P*	30	*R* to *S*	30	*R* to *S*
D	Oxaluma............	24 to 30	*K* to *L*	24 to 30	*K*	30 to 46	*J* to *K*
E	Carbo-alumina......	16 to 46	*E* to *M*†	24 to 46	*E* to *G*†	24 to 46	*E* to *H*†
F	Alundum...........	14 to 24	*J* to *K*	14 to 30	*H* to *K*‡	14 to 30	*H* to *K*‡
G	Rex.................	30 to 60	*M* to *P*	36 to 46	*M* to *P*	36 to 46	*M* to *P*
I	Corundum..........	36 to 46	*E*	46 to 60	D_3 to *E*	36	*E*
J	Alowalt.............	36 to 46	2½ to 3	36 to 46	2 to 2¾	36 to 46	2 to 3
	Grinding Wheels of Ring Type						
A	Boro-carbone........	24	*J*†	20 to 30	*G* to *I*†	24	*J*†
B	Corundum..........	58-20 to 58-30	¾ to 1½†	24 to 36	½ to 1†	58-20 to 58-30	½ to 1†
C	Aloxite..............	24	*N* to *P*	30	*R* to *S*	30	*R* to *S*
D	Oxaluma............	24 to 30	*K* to *L*	24 to 30	*K*	30 to 46	*J* to *K*
E	Carbo-alumina......	16 to 24	*E* to *G*†	24 to 46	*E* to *G*†	24 to 46	*E* to *H*†
F	Alundum...........	14 to 36	*I* to *K*‡	14 to 36	*G* to *K*‡	14 to 36	*G* to *K*‡
G	Rex.................	24 to 46	*M* to *M*¾	36 to 46	*M* to *P*	36 to 46	*M* to *P*
I	Corundum..........	36	D_3	36 to 46	D_2	36	D_3
J	Alowalt.............	36 to 46	2½ to 3	36 to 46	2 to 2¾	36 to 46	2 to 3

* For list of grinding wheel manufacturers which letters represent, see foot-note, Table I.
† Grinding wheels bonded by silicate process.
‡ Vitrified or silicate bond.

NOTE. The number 58 preceding, in some cases, the grain sizes, indicates a special manufacturing process for the abrasive listed.

The nature of the material has also a governing effect on the grade and grain to be used, as well as the abrasive from which it is made. For grinding soft steel, the bond should be harder than for grinding hard steel. Hardened steel has a tendency to glaze the wheel much more rapidly than soft work, and glazing is one of the greatest difficulties met with in grinding. Wheels made from aluminum-oxide abrasives are excellent to use for steel. For grinding cast iron, carbide of silicon abrasives are more satisfactory; carbide of silicon abrasives can also be used on brasses and bronzes, aluminum, nickel-bronze, and government-bronze.

The rigidity of a machine has about as much to do with the selection of the grade and grain of the wheel as any other one factor. The fact is often overlooked that a machine which is not rigid should use a harder wheel than one which is stiff and rigid. The greater the rigidity of the machine, the softer the grade and coarser the grain of the wheel should be. Of course, the rigid machine also has the advantage that enables it to remove the stock with rapidity and without chatter marks.

For rough internal grinding, it is generally advisable to use a wheel of coarse grain and soft bond, because of the greater cutting capacity of the wheel; under average conditions, a wheel of finer grain and harder bond would be better for finishing. In commercial grinding, however, the time necessary to change the wheels for roughing and finishing would more than overbalance the gain in production by using a wheel best suited to both purposes, so that a wheel is generally selected which will be fairly suitable for both roughing and finishing. When a good finish is desired, it is the general practice to dress the wheel after taking the roughing cut, by passing a diamond slowly in front of the wheel.

Table III gives the grain and grade of grinding wheels for the internal grinding of carbon steel (soft and hardened), alloy steels, cast iron, brass, bronze, and aluminum. It is practically impossible to give a definite grain and grade unless all the conditions regarding the work and the machine upon which the wheels are to be used are known.

Wheels for Surface Grinding. — In surface grinding, the area of contact between the wheel and work is of greater importance in the selection of wheels than for either cylindrical or internal grinding. As previously mentioned in connection with Fig. 1, a disk wheel may be used, as shown at *B*, or a ring or cylinder wheel may be used on work that is either wider or narrower than the wheel diameter, as shown at *D*. In Tables IV to IX, inclusive, are given wheel selections for surface grinding different materials with the disk type and ring or cylinder type of grinding wheel.

Table V. Grain and Grade of Grinding Wheels for Surface Grinding — 2

Grinding Wheels of Disk Type

Wheel M'n'f'r*	Abrasive	Bonding Process	Cast Iron		Cast Brass and Bronze	
			Grain	Grade	Grain	Grade
A	Carbide of silicon	Vitrified	30 to 46	*L* to *M*	30 to 46	*K* to *L*
B	Carbolite	Vitrified	36 to 46	*K* to *L*	36 to 60	*K* to *L*
C	Carborundum	Vitrified	24	*P* to *S*	30	*P* to *S*
D	Carborundum	Vitrified	20 to 30	*L* to *M*	....	....
D	Oxaluma	Vitrified	....	....	20 to 24	*K* to *M*
E	Carbo-alumina	Silicate	16 to 36	*D* to *H*	24 to 46	*F* to *H*
F	Crystolon	Vitrified or silicate	20 to 30	*I* to *K*	....	....
F	Crystolon	Vitrified	....	....	20 to 30	*I* to *K*
G	Corex	Vitrified	20 to 26	*M* ½ to *P*½	30 to 36	*M* ½ to *P*
I	Carbolon	Vitrified	20 to 36	E_3 to *E*	....	....
I	Corundum	Vitrified	....	....	24 to 36	E_3 to *E*
J	Carbowalt	Vitrified	24 to 36	2 to 3	....	....
J	Carbowalt	Three processes	....	....	24 to 36	2 to 3

Wheel M'n'f'r*	Abrasive	Bonding Process	Cast Aluminum		Malleable Iron Castings	
			Grain	Grade	Grain	Grade
A	Carbide of silicon	Elastic	30 to 36	2 *E* to 3 *E*	....	....
A	Boro-carbone	Vitrified	....	....	24 Comb.	*M*
B	Carbolite	Elastic	36 to 60	1½*E* to 2 *E*	....	....
B	Carbolite	Vitrified	....	....	30 to 36	*K* to *L*
C	Carborundum	Elastic	36	5 to 6	....	....
C	Aloxite	Vitrified	....	....	16 to 24	*G* to *H*
D	Oxaluma	Vitrified	20 to 24	*K* to *M*	14 to 20	*Q* to *R*
E	Carbo-alumina	Silicate	20 to 36	I_1 to M_1	16 to 30	*F* to *H*
F	Crystolon	Elastic	24 to 46	1½ to 2½	....	....
F	Alundum	Vitrified	....	....	14 to 36	*I* to *K*†
G	Corex	Vitrified	36 to 46	*M* to *P*	....	....
G	Rex	Vitrified	....	....	36 to 60	*M* ½ to *P*
I	Carbolon	Elastic	20 to 36	4½	....	....
I	Corundum	Vitrified	....	....	16 to 30	F_1 to E_3
J	Carbowalt	Elastic	24 to 36	1¾ to 2	....	....
J	Alowalt	Vitrified	....	....	24 to 36	2½ to 3

* For a list of grinding wheel manufacturers which letters represent, see foot-note, Table I.

† For rough castings, unannealed, use crystolon; vitrified, grain 20 to 30, grade *J* to *M*.

Table VI. Grain and Grade of Grinding Wheels for Surface Grinding — 3

Grinding Wheels of Ring Type

Wheel M'n'f'r*	Abrasive	Bonding Process	Cast Iron		Cast Brass and Bronze	
			Grain	Grade	Grain	Grade
A	Carbide of silicon..	Vitrified	24–30	*I* to *J*	20 to 30	*I* to *J*
B	Carbolite..........	Vitrified	16–24	*I* to *K*	20 to 30	*I* to *K*
C	Carborundum.....	Vitrified	24	*P* to *S*	30	*P* to *S*
D	Carborundum....	Vitrified	20 to 30	*L* to *M*	....	....
D	Oxaluma........ .	Vitrified	....	....	20 to 24	*K* to *M*
E	Carbo-alumina....	Silicate	16 to 24	*E* to *G*	16 to 36	*G* to *K*
F	Crystolon.........	Vitrified or silicate	14 to 30	*I* to *K*	....	....
F	Crystolon.........	Vitrified	....	....	14 to 30	*I* to *L*
G	Corex.............	Vitrified	20 to 36	*M* ½ to *P*½	30 to 36	*M* ½ to *P*
I	Carbolon..........	Vitrified	30	*E*2	....	....
I	Corundum........	Vitrified	....	....	30	*E*2
J	Carbowalt.........	Vitrified	24 to 36	2 to 3	....	....
J	Carbowalt..... ...	Three processes	....	....	24 to 36	2 to 3

Wheel M'n'f'r*	Abrasive	Bonding Process	Cast Aluminum		Malleable Iron Castings	
			Grain	Grade	Grain	Grade
A	Carbide of silicon .	Elastic	24 to 30	¾ *E* to 1 *E*	....	....
A	Boro-carbone.....	Silicate	....	....	20 to 24	*J*
B	Carbolite..........	Vitrified	20 to 30	*I* to *K*	14 to 24	*I* to *K*
C	Carborundum.....	Elastic	36	5 to 6	....	....
C	Aloxite............	Vitrified	....	....	16 to 24	*G* to *H*
D	Oxaluma..........	Vitrified	20 to 24	*K* to *M*	14 to 20	*Q* to *R*
E	Carbo-alumina....	Silicate	20 to 36	*H* to *K*	16 to 30	*E* to *G*
F	Crystolon.........	Vitrified	16 to 30	*H* to *K*	....	....
F	Alundum.........	Vitrified or silicate	....	....	14 to 30	*H* to *L*†
G	Corex.............	Vitrified	36 to 46	*M* to *P*	....	....
G	Rex...............	Vitrified	....	....	36 to 60	*M* ½ to *P*
I	Carbolon.........	Elastic	20 to 36	4	....	....
I	Corundum	Vitrified	.. ..	....	24	*E*1
J	Carbowalt........	Elastic	24 to 36	1¾ to 2	... .	....
J	Alowalt..........	Vitrified	....	....	24 to 36	2 to 3

* For a list of grinding wheel manufacturers which letters represent, see foot-note, Table I.

† For rough castings, unannealed, use crystolon, grain 16 to 24, grade *J* to *M*.

Table VII. Wheels for Grinding Narrow Surfaces on Vertical Surface Grinder *

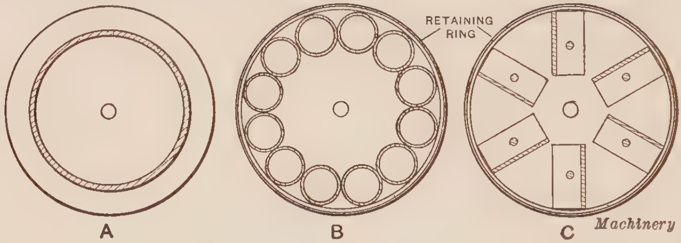


Illustration Indicates General Class of Work for which the Wheels listed are adapted

Material	Abrasive	Bonding Process	Width of Wheel Rim	Grain	Grade
Cast Iron †........	Carbolite	Vitrified	1¼	30	*I*
	Carbolite	Vitrified	1½	24	*I*
	Crystolon	Vitrified	1¼	30	*I*
	Crystolon	Vitrified	1½	24	*J*
Chilled Cast Iron..	Carborundum	Vitrified	1½	20	*I*
Soft Steel	Corundum	Silicate	1¼	58–30	I
	Alundum	Silicate	1¼	38–30	*I*
	Alundum	Silicate	1¼	38–30	*J*
Hardened Steel....	Corundum	Silicate	1¼	30‡	¾
	Alundum	Silicate	1¼	38–30	*H*
Aluminum.........	Alundum	Vitrified	1½	38-14	*I*

* Recommended by the Blanchard Machine Co.

† For brass, bronze, and similar alloys of low tensile strength, use same wheels as for cast iron. For hard bronze use same wheels as for soft steel.

‡ No. 46 grain and same grade is also used on narrow surfaces to obtain a smoother finish.

Note. The numbers 38 and 58 preceding, in some cases, the grain sizes, indicate a special manufacturing process for the abrasive listed.

For grinding with disk wheels used on the planer type of surface grinding machines, the grain commonly varies from 46 to 60, whereas, the grade is about H for hardened steel when using wheels made from aluminum-oxide abrasives; for hardened high-speed steel or very thin pieces of hardened carbon steel, the bond of the wheel should be about grade G, the same grain being used. For grinding cast iron, wheels made from

Table VIII. Wheels for Grinding Medium Surfaces on Vertical Surface Grinder *

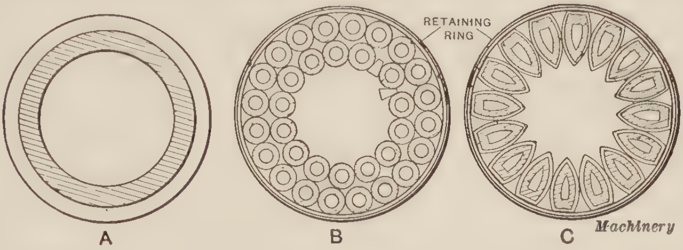


Illustration indicates General Class of Work for which the Wheels listed are adapted

Material	Abrasive	Bonding Process	Width of Wheel Rim	Grain	Grade
Cast Iron†	Carbolite	Vitrified	1½	20	*H*
	Carbolite	Vitrified	1½	14	*I*
	Crystolon	Vitrified	1½	20	*H*
	Crystolon	Vitrified	1½	14	*I*
Chilled Cast Iron	Carbolite	Vitrified	1½	20	*H*
Soft Steel	Corundum	Silicate	1½	58–24	1
	Alundum	Silicate	1½	38–24	*H*
Hardened Steel	Corundum	Silicate	1¼	30	½
	Alundum	Silicate	1¼	38–24	*H*
High-speed Steel	Corundum	Silicate	1½	58–24	¾
Aluminum	Alundum	Vitrified	1½	38–14	*I*
Fiber	Alundum	Silicate	1½	38–24	*G*

* Recommended by the Blanchard Machine Co.

† For brass, bronze, and similar alloys of low tensile strength, use same wheels as for cast iron. For hard bronze use same wheels as for soft steel.

NOTE. The numbers 38 and 58 preceding, in some cases, the grain sizes, indicate a special manufacturing process for the abrasive listed.

carbide of silicon abrasives are used, the grain being about 36 and the grade J.

When grinding with cylinder or ring wheels, the greatest trouble experienced is in getting rid of the chips and preventing heating of the work. The grinding of a continuous flat surface with a ring wheel makes it necessary to do the grinding with

Table IX. Wheels for Grinding Broad Surfaces on Vertical Surface Grinder *

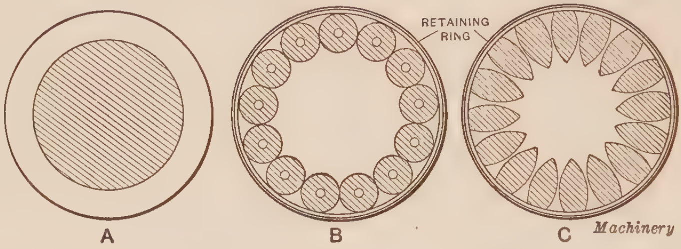


Illustration indicates General Class of Work for which the Wheels listed are adapted

Material	Abrasive	Bonding Process	Width of Wheel Rim	Grain	Grade
Cast Iron†	Carbolite	Vitrified	1½	14	*H*
	Crystolon	Vitrified	1¼	24	*G*
Soft Steel	Corundum	Silicate	1½	58–14	¾
	Alundum	Silicate	1½	38–14	*I*
	Alundum	Vitrified‡	1½	38–14	*I*
Hardened Steel	Corundum	Silicate	1¼	24	⅝
	Alundum	Silicate	1¼	38–24	*G*
High-speed Steel	Corundum	Silicate	1½	58–24	⅝

* Recommended by the Blanchard Machine Co.

† For brass, bronze, and similar alloys of low tensile strength, use same wheels as for cast iron. For hard bronze use same wheels as for soft steel.

‡ Wheels made by vitrified process are used only for roughing purposes.

NOTE. The numbers 38 and 58 preceding, in some cases, the grain sizes, indicate a special manufacturing process for the abrasive listed.

a rapid work speed and shallow cuts, using wheels of relatively coarse grain and soft bond. When the work is narrow in proportion to the diameter of the wheel, as shown by the dotted lines at *D* in Fig. 1, there is less trouble with chips.

The wheels used on the Blanchard belt-driven grinders are of the cylinder type, 16 inches in diameter, 5 inches high, and of widths of rims varying from 1¼ to 1½ inch. In selecting wheels for this machine, the two most important factors to consider are the material to be ground and the amount of surface presented to the wheel. For grinding cast iron, aluminum, brass, and alloys of low tensile strength, wheels made from carbide of silicon abrasives and having a vitrified bond have given the best results. For steel, either hard or soft, and for the tougher and stronger bronzes, wheels made from aluminum-oxide abrasives and bonded by the silicate process are used. As a general rule, hard-bond wheels should be used on soft, tough stock and soft-bond wheels on hardened stock.

The surface to be considered in grinding on a surface grinder is that presented to the wheel by a group of pieces that are held on the chuck at one time. These have been divided into three classes, *viz.*, narrow, medium, and broad surfaces. The wheels recommended by the Blanchard Machine Co. for these various classes of work are given in Table VII, VIII, and IX, respectively. These tables will serve as a general guide in selecting the wheels. The wheels listed are those made by the American Emery Wheel Works and the Norton Co. The reason for this is that a large number of tests have been made with these particular wheels on the work specified.

The illustration shown in connection with Table VII is given to indicate "narrow surfaces." At *A* is shown a ring with a $\frac{3}{4}$-inch rim. At *B* is shown a group of rings with walls $\frac{1}{4}$ inch wide, whereas, at *C* are shown castings having ribs $\frac{1}{2}$ inch wide and small bosses that must be ground. These are given to indicate, in a general way, what is meant by "narrow surfaces." The illustration accompanying Table VIII shows examples of work to indicate medium surfaces. Ring-shaped parts, like the one shown at *A*, may vary in width from 2 to 3 inches: the parts shown at *B* are washers $3\frac{1}{2}$ inches in diameter with a 2-inch hole, leaving a wall of $\frac{3}{4}$ inch. Thirty-four pieces are held on the table. If a single instead of a double row of pieces were held on the chuck at one time, this class of work would be considered as having narrow surfaces. The castings shown at *C* have a ground surface about $1\frac{1}{4}$ inch wide and 16 pieces are held on the table.

Points on Selection of Grinding Wheels. — A few of the most important points to consider in making a selection of the correct grain and grade of wheel to use are given in the following:

1. For materials of low tensile strength, use grinding wheels made from the carbide of silicon abrasives. For materials of high tensile strength, use grinding wheels made from aluminum-oxide abrasives.

2. If a wheel glazes over, fills, and cuts slowly, it is too hard — try one or two grades softer.

3. If a wheel wears away too fast, wears out of round or quickly loses its shape, it is too soft.

4. Increasing the speed of a wheel will make it act like a wheel of harder grade, and decreasing the speed will make it appear softer. A wheel should be speeded up as the diameter is reduced by wear, in order to maintain the proper surface speed.

5. The greater the surface contact between the wheel and the work, the softer the grade of the wheel should be.

6. In cylindrical grinding, work of large diameter will require a softer wheel than work of small diameter. Pieces which have a narrow surface or edge to be ground need a harder wheel than wide surfaces.

7. In cylindrical grinding, increasing the work speed tends to wear away the wheel faster. Vibration due to worn bearings, lack of rigidity in the machine, or a shaky floor has the same effect.

8. The use of water permits of the use of a wheel of slightly harder bond and improves the finish of the work. It also prevents overheating of the work and the resulting distortion.

9. A wheel is the most efficient when it is just soft enough to cut freely without excessive wear and not hard enough to cause glazing.

10. To preserve some special shape of face, a relatively hard wheel should be used — generally a wheel of combination grain is recommended for form grinding.

CHAPTER VIII

GRINDING WHEEL TRUING DEVICES

A GRINDING wheel should run true and have an even bearing on the surface of the work, the face of the wheel being parallel with the surface being ground; it is especially important to have a true, even wheel-face when taking a finishing cut. The only satisfactory method of truing a wheel, for machine grinding operations, is by the use of a diamond tool. This tool is clamped to the footstock of the machine (as shown in Fig. 1) or in a special holder attached to the table, and the stroke is adjusted so that the diamond point will clear the wheel-face on each side. The wheel, which should revolve at the speed required for grinding, is then trued by bringing it into contact with the diamond as the latter travels back and forth. Very light cuts should be taken and plenty of water used to keep the diamond cool. The diamond tool should be held with the point quite close to the clamp, or point of support, in order to reduce vibration and give a smooth accurate wheel surface. Diamond tools usually have round shanks, to permit clamping them in different positions, so that the wear on the diamond will not be confined to one or two points. When truing the wheel, light cuts should be taken and the diamond traversed across the face with a uniform speed. The number of times that the wheel has to be trued depends upon the character of the work and the kind of wheel used. If it is necessary to remove considerable stock, the wheel may have to be trued before taking each finishing cut, provided the roughing and finishing operations are performed successively. When a number of duplicate parts are ground, this is avoided by first rough-grinding them all and then truing the wheel once for finishing the entire lot, or as many parts as the wheel will grind satisfactorily.

Glazed and Loaded Grinding Wheels. — The wheels used for machine grinding not only require truing but "re-sharpening," when they will not cut effectively, owing to glazing and loading; this re-sharpening is done by removing the dull cutting points or grains of abrasive, a diamond tool generally being used. The difference between a glazed and loaded wheel is as follows: The cutting face of a loaded wheel has particles of the metal being ground adhering to it, the openings or pores of the wheel-face having been filled up with metal, thus preventing the wheel from cutting freely. A glazed wheel is one having cutting particles that have become dull, or worn down even with the bond, the bond being so hard that it does not allow the dulled cutting particles to be torn out of the wheel. Continued work with a wheel that glazes increases the smoothness of the wheel-face and decreases its cutting capacity.

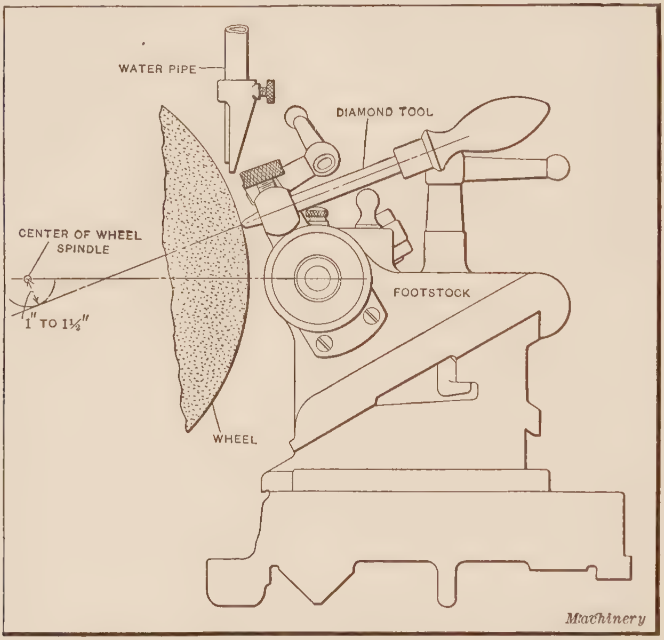


Fig. 1. Position of Diamond Tool for Truing Face of Grinding Wheel

On cylindrical grinding, loading may be caused by using a wheel of too hard a bond and running it too slowly. It may also be caused by taking cuts that are too deep. When a hard wheel is revolved at too slow a speed with plenty of power, the grains withstand the excessive cuts without breaking away, and thus pick up the metal. The remedy for loading is to increase the speed of the wheel or use a softer wheel. Glazing takes place when a wheel is too hard or revolves at too fast a speed. The remedy for glazing is to decrease the speed or use a softer wheel. Loading and glazing of the wheel makes excessive truing necessary and this, of course, means greater wheel wear. For truing a hard wheel, a sharper diamond is used than for truing a softer wheel. The reason for this is that a sharp diamond leaves the surface of the hard wheel with more clearance, and, consequently, this surface will cut for a greater length of time. Increasing the work speed also makes a wheel of hard bond or one having a tendency to glaze cut more freely.

Selecting Diamonds for Wheel Truing. — For the truing and sharpening of wheels used on grinding machines, the most satisfactory tool to use is the diamond. Carbon, carborundum, alundum blocks, etc., are used, to some extent, to remove a glazed surface, but for truing, the diamond is the most satisfactory. The diamonds generally used in tools for truing grinding wheels are of two kinds, the carbon or black diamond and bort. The black diamond rarely has any visible crystallization; its color varies, but it is often of a dark purple brown. The bort is a semi-transparent stone or an imperfect "brilliant." It is not as hard as the black diamond and is also considerably lower in price. For truing soft wheels, bort can be used, but, as a general rule, the black diamond is cheaper in the end.

One prominent manufacturer states that, in his experience, the Brazilian bort or brownstone, sometimes called South African "premiers," is the best for truing grinding wheels. These stones are considerably cheaper than the black diamond. For instance, a brown diamond can be purchased for fifteen dollars, equal in size and weight to a black diamond costing between seventy and seventy-five dollars. In selecting the diamond, care should be taken to see that no seams appear, as such stones are liable to crack along the seams. The smooth "skin" stone is the one most likely to prove satisfactory. The more points a stone has, the better it is adapted to the truing of grinding wheels.

Setting Wheel-truing Diamonds. — In order to present the diamond to the work, it is necessary that it be held in a holder. Copper, brass, or soft steel rods are generally used, and the diamond is either held in its seat by peening over the end of the bar or pouring in melted spelter. In holding diamonds by means of spelter, the latter should be poured into the hole first, before the diamond is inserted. If the diamond is inserted and the spelter then poured in, it is difficult to get the spelter to go to the bottom of the diamond and hold it rigidly. The best method is to first drill the hole slightly deeper than the extreme height of the diamond and of a size that will admit the diamond freely. Then the hole should be closed in just enough to make it out of round. The spelter is then poured into the hole, filling it completely, and the diamond, held in a pair of tweezers, is inserted into the liquid spelter in the hole. After the spelter has cooled, the end of the rod, in which the diamond is located, can be shaped in the customary manner.

Another method, which is quicker and which is also in general use, is to drill a hole in a piece of soft steel slightly larger and deeper than the diamond. The diamond is then inserted and the end of the rod peened over, entirely covering the diamond. The peening is done with a small flat-headed chisel, or a set, and should be done carefully, to avoid breaking the diamond. As the result of peening, the diamond is covered entirely by the metal and this is partly removed by grinding, exposing the diamond point. Copper rods are also used for holding diamonds which are retained by peening.

Still another method of setting a black diamond, which differs slightly from that just described, is as follows: First, a hole is drilled in the end of a $\frac{3}{8}$-inch soft steel rod just large enough to admit the diamond. The diamond is then placed in the hole, with the largest end at the bottom, and the metal is peened around sufficiently to hold the diamond in place. The diamond with the holder is then heated to a white welding heat, and, by means of light blows with a small hammer, the metal is closed in around the diamond. The end of the holder is then ground away until the diamond touches the wheel.

Methods of Truing Grinding Wheels. — On modern cylindrical and surface grinding machines, a relatively coarse-grain, soft-bond wheel is commonly used for removing the greater part of the material (especially in commercial grinding), and this wheel is usually of so coarse a grain that it will not produce a fine enough finish when the wheel-face is sharp, as for rough-grinding. For finishing, the method adopted is as follows: After removing most of the material, leaving sufficient for finishing, the face of the wheel is trued with a diamond that does not have a very sharp point, but, preferably, has a rounded or rather dull point. By traversing this diamond slowly past the face of the wheel, a surface is produced on the wheel which is smooth and, at the same time, true. This surface is a temporary one on a coarse wheel; by carefully feeding the wheel in for the finishing cut, so as not to disturb the surface, a fine finish is secured. The quality of the finish on the work depends largely on the quality of the surface of the wheel. When a second piece is to be rough-ground, the wheel is fed in rapidly, taking a heavy cut, and the smooth surface entirely disappears.

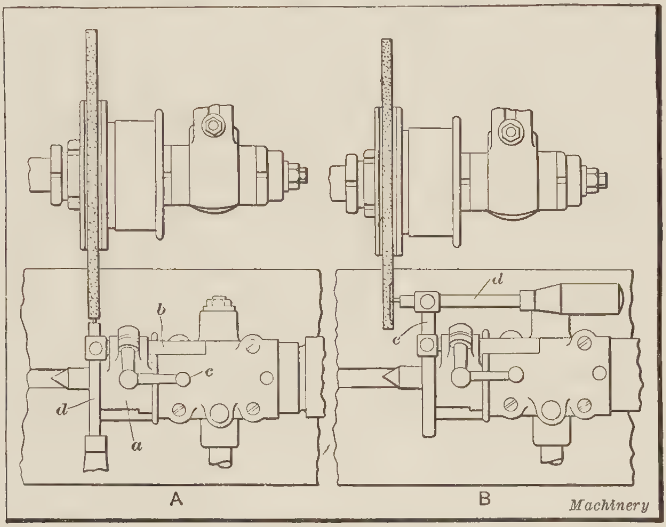


Fig. 2. Common Method of Truing Face and Sides of Grinding Wheel

The method of truing a hard-bond, fine-grain wheel is just the reverse from that described. Instead of using a diamond having a blunt rounded point, it is necessary to have a sharp point, in order that the surface may be roughed up. Water must flow on the diamond continually, and, instead of a very slow traverse of the diamond past the wheel, the diamond is traversed rapidly, taking light cuts. For accurate cylindrical grinding, all other factors being considered, the most profitable wheel to use is often the one which requires frequent truing.

Angular Position of Diamond Tool. — In truing the average grinding wheel, and especially when using a comparatively hard-bond wheel on a cylindrical grinding machine, it is necessary

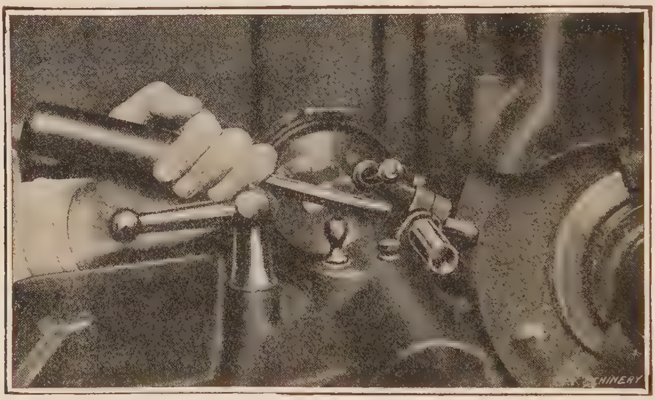


Fig. 3. Truing Face of Grinding Wheel with an Ordinary Diamond Tool

to maintain new cutting facets or points on the diamond to present to the grinding wheel. In order to do this, it is necessary to present the diamond point at a certain angle to the face of the wheel. The diagram, Fig. 1, illustrates a standard diamond truing tool being applied to a grinding wheel. In this case, it will be noticed that the diamond holder is held at such an angle to the face of the grinding wheel that, by continuing the line representing the axis of the diamond holder, it coincides with an arc of from 1 to $1\frac{1}{2}$ inch radius scribed from the center of the wheel-spindle. By holding the diamond in this position, it is possible to secure the new cutting facets. For truing soft-bond wheels, it is sometimes advisable to use a diamond that has a rounded point, as previously mentioned, and, in this case, the diamond need not be presented at an angle but can be held in a horizontal position.

Types of Wheel-truing Fixtures. — Fig. 2 shows a common method of applying a diamond tool to the face and sides of the grinding wheel. At *A* is shown the method of applying the diamond tool for truing the face of the wheel. A diamond holder *a* is held on the footstock of the grinding machine and carries a rod *b* which is clamped in position by means of lever *c*. The rod or extension holder *b*, in turn, carries a diamond holder *d*.

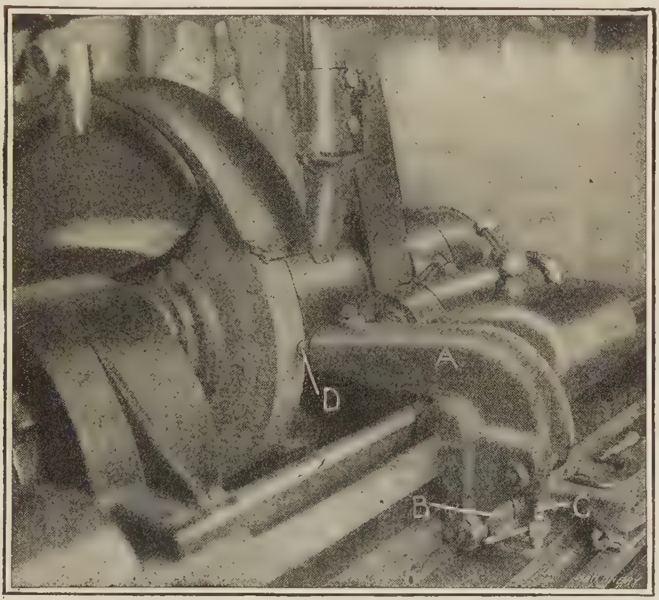


Fig. 4. Wheel-truing Device which is so located that Wheel is in Position for Grinding after being Trued

To apply this type of wheel-truing device to the side of the wheel, it is necessary to insert an additional holding rod *e*, which occupies the same position as the diamond holder at *A*. Grinding wheels are trued on the side when it is necessary to face a shoulder. Where the opposite side of the wheel to that shown in the illustration is to be trued, the wheel is moved over, and the position of diamond holder *d* is reversed in holder *e*.

Fig. 3 shows the wheel-truing device illustrated in Fig. 2

being applied to the face of the grinding wheel. The diamond holder is held close up to the diamond, in order that the holder be retained rigidly, to prevent chatter and chipping of the diamond point. In applying the diamond, where an ordinary finish is desired on the face of the wheel, usually, the power feed is thrown in to traverse the diamond in front of the wheel.

With some of the wheel-truing devices on the market, it is necessary to change the position or location of the wheel in relation to the work, in order to true its face. This necessitates re-setting each time the wheel is trued. A wheel-truing device which overcomes this objectionable feature is illustrated in Fig. 4. The cast-iron bracket *A* is held to the front of the table of a Norton plain grinding machine. The method of clamping is simple, there being a small shoe *B*, hinged in the lower portion of the bracket, and against which an adjustable clamping bolt *C* rests. This device is effective in holding the bracket rigidly in position. The diamond holder *D* is held in the front end of the bracket by a set-screw, as shown. This device is used when there is no work between the centers.

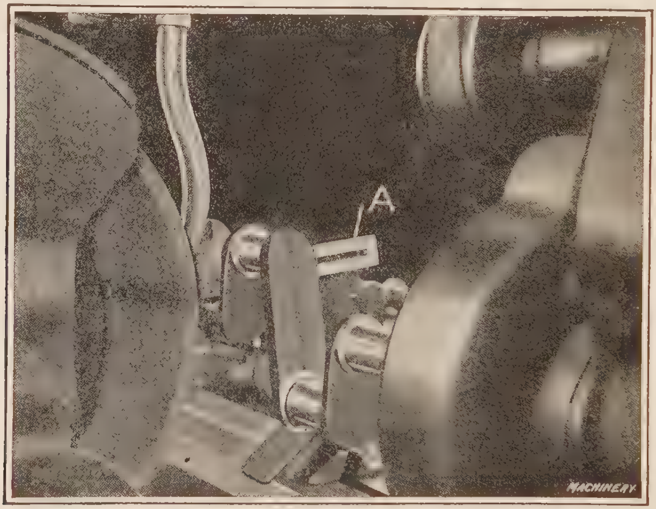


Fig. 5. Simple Form of Wheel-truing Tool applied to Landis Crank Grinder

When first setting up the machine, the diamond point is located so that it trues the wheel in such a position in relation to the centers that the work, when placed on the centers, is ground to practically the required diameter. The setting of the diamond is not changed after this, and, as the wheel is worn down by frequent truing, its relation to the centers is approximately maintained. In this way, very little adjustment of the wheel slide is necessary, which reduces the time usually spent in truing the wheel. In order to take care of small and large diameter work, brackets *A* are made in several lengths, so that it is not necessary to have the diamond holder project too far from the bracket, which would be objectionable.

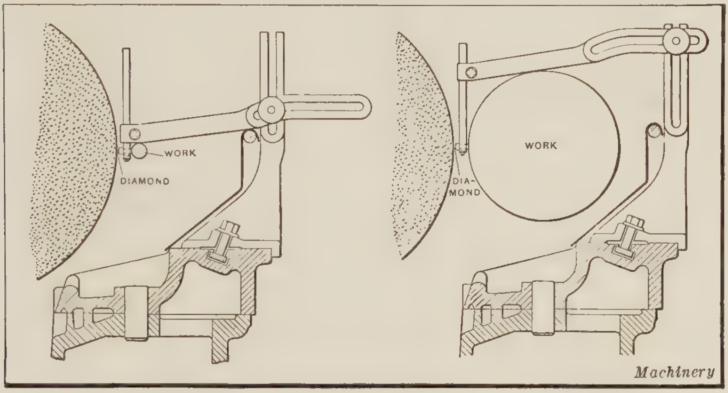


Fig. 6. Wheel-truing Fixture applied to Work of Small and Large Diameters

Another wheel-truing device is shown in Fig. 5 applied to a Landis crankshaft grinder. The holder *A* has an elongated slot fitting the body of a set-screw that clamps it to the face of the steadyrest casting. With this device, it is not necessary to remove the work from the centers to true the face of the wheel. In use, the diamond holder *A* is released and the latter pushed in between the throws of the crankshaft; the wheel slide is then traversed to true the face of the wheel. After truing, the set-screw is released and holder *A* pulled back out of the way. This device has proved very effective in quickly truing the wheel on a Landis crankshaft grinding machine. A wheel-truing fixture which is somewhat like the one just described is shown in Fig. 6; the two views illustrate its application in connection with work of small and large diameter. This was also designed for the Landis machines.

Multiple Diameter Wheel-truing Attachment. — The application of wide face grinding wheels to the production of shoulder shafts, or other multiple diameter work, has resulted in the use of attachments either for accurately locating the wheel or truing the face of the wheel to different diameters. When the sum of the lengths of all the diameters to be ground is less than the width of the wheel, it is most economical to true several diameters along the wheel-face. The work is then ground in the ordinary manner by simply feeding the wheel straight in without any lateral traverse. If the difference in size between the various diameters is small, it is not economical to produce these different shoulders in the rough-turning operation; the part should be turned straight and the wheel formed to produce the slight diameter variations. This imposes a little more work on some parts of the wheel, and more frequent truing will be required, but this usually is cheaper than producing the small differences in the diameter by turning.

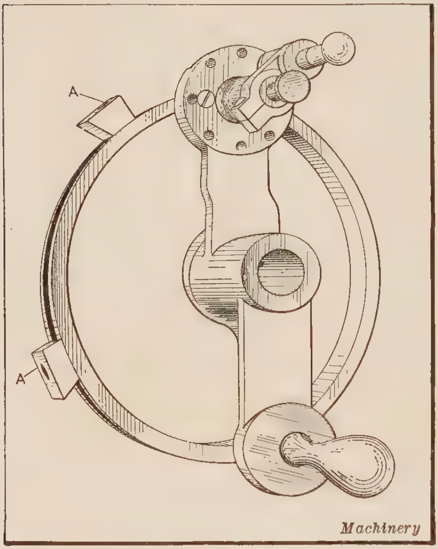


Fig. 7. Special Index-crank applied to Norton Machines for Truing Different Diameters on Wheel-face

When various portions of a shaft are of such length that the entire face of the wheel does not cover them, the work must be traversed and means must be employed for accurately locating the wheel for each diameter. An attachment for doing this is shown in Fig. 7. This device is attached to the regular index-crank of a Norton plain grinding machine. It has a metal ring, in which a dovetailed slot has been turned, and in which blocks *A* are held by means of screws. These are located around the periphery of the ring in the desired position. By numbering or lettering these blocks and correspondingly numbering or lettering the working drawings, the operator can readily determine just how far in to move the wheel for grinding the various diameters.

In order to true the wheel, so as to grind two different diameters at one setting, the procedure to follow is to first true the wheel straight across the face with the first block resting against a stop-arm on the machine. Then the ring should be turned around until the second block rests against the stop-arm, thus advancing the wheel toward the diamond a certain predetermined amount. If now the diamond is traversed along the wheel-face for the required distance, part of the wheel-face will be reduced in diameter; therefore, if the wheel is brought straight in on the work, it will produce two diameters, the larger of these being made by the smaller diameter on the wheel.

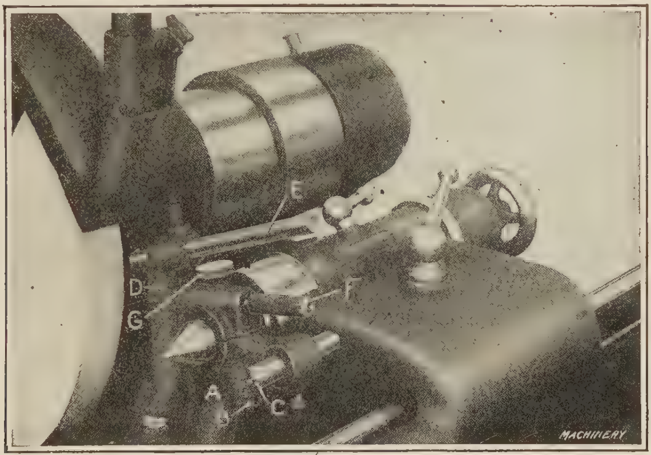


Fig. 8. Radius Wheel-truing Device for Cylindrical Grinding Machines

Another form of multiple diameter wheel-truing device consists of a block which is bored out to fit over the front end of the footstock to which it is clamped. The top face of this block has a dovetail groove to receive a second block which carries two separate diamond holders. These holders are adjusted by means of graduated collar screws, so that movements of 0.001 inch can be obtained. In use, this wheel-truing device is brought over in contact with the face of the grinding wheel, and then a stop on the front of the machine is set and the table traversed back and forth until the wheel is trued. The relative positions of the diamond points regulate the diameters to which the wheel is trued.

Radius Wheel-truing Devices. — In grinding certain classes of work, it is necessary to form a fillet near a shoulder, and some type of radius wheel-truing device is used. Fig. 8 shows a simple but effective device which can be used either for truing the radius on the wheel or for truing the wheel parallel with the axis. Bracket *A* is clamped to the footstock center by means of a clamping screw *B* and also has a projecting arm for fastening it to stud *C*. The radius wheel-truing fixture proper consists of a bracket *D* capable of swiveling in the seat provided in the lower end of bracket *A*. Bracket *D* carries the diamond holder *E*, that is held in place by a set-screw, as shown. It is also provided with a slot in which a plug *F* fits.

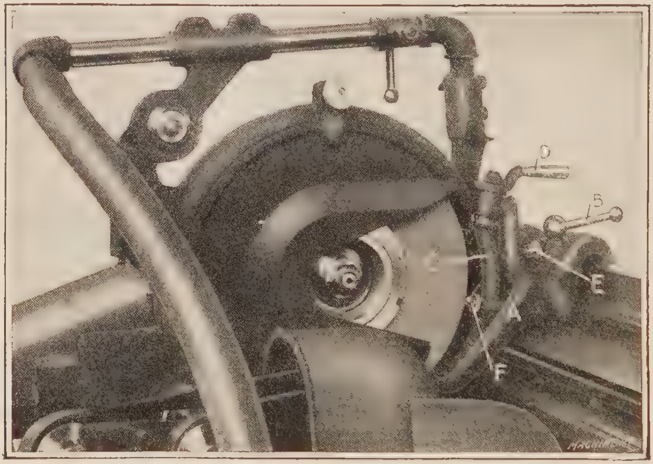


Fig. 9. Another Design of Radius Wheel-truing Device

In using this device, for producing a radius, thumb-screw *G* is released and plug *F* pulled back. This allows a free swinging movement of bracket *D* and, by gripping holder *E*, the operator can true a radius on the wheel. To true the face parallel with the grinding machine centers, plug *F* is pushed in, thumb-screw *G* tightened, and then the table traversed, moving the diamond point across the wheel-face.

The radius wheel-truing device shown in Fig. 9 differs from that shown in Fig. 8 chiefly in the method of clamping it to the machine and in the manner in which the diamond holder is held and rotated. Bracket *A* is clamped to the grinding machine table by a clamping lever *B*. The lower part of bracket *A* carries the diamond-holder bracket *C* in the manner illustrated. This bracket can be swung by operating lever *D* when it is necessary to true a radius on the wheel. For parallel truing of the grinding wheel-face, plug *E* is pushed in and fits in a hole provided in bracket *C*, holding the bracket rigidly in position. The diamond is held in the holder *F*, the external diameter of which is threaded to receive a nut used for adjusting purposes.

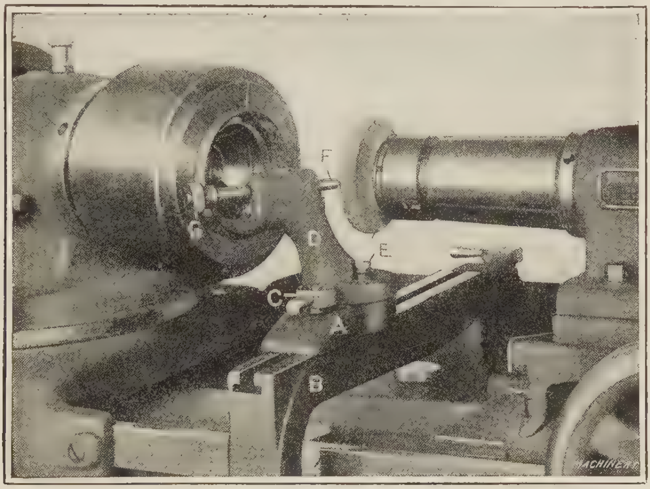


Fig. 10. Radius Wheel-truing Device for Internal Grinding Machine

Radius Truing Device for Internal Grinding Wheel. — A simple device for truing wheels for internal grinding on a Heald internal grinding machine is shown in Fig. 10. Bracket *A* is provided with a locating key and is held to the yoke *B* by means of a clamping bolt and nut *C*. The diamond holder proper is held in a bracket *D* that is free to swivel on the base when plug *E* is lifted up. When this plug is pushed down, the device can be used for truing the wheel parallel with the axis of the spindle. The diamond is held in a holder *F*, the rear portion of which is threaded, enabling it to be adjusted by turning knob *G*, in order to true the wheel to various radii.

Radius Truing Device for Surface Grinders. — An interesting wheel-truing device for use on the Norton surface grinding machine is shown in Fig. 11. The main bracket *A* has two extension members, one of which acts as a fulcrum point for the wheel-truing holder *B*, whereas, the other extension holds a plug *C* for adapting this device for truing the wheel straight. The diamond holder *D* is held in bracket *B* and is adjustably mounted. In using this device, to true a radius on the corner of a wheel, thumb-screw *E* is released and plug *C* pulled down. This allows a free oscillating movement of holder *B*. When a straight face is to be trued on the wheel, plug *C* is pushed up until it contacts with a hole in bracket *B*, then screw *E* is tight-

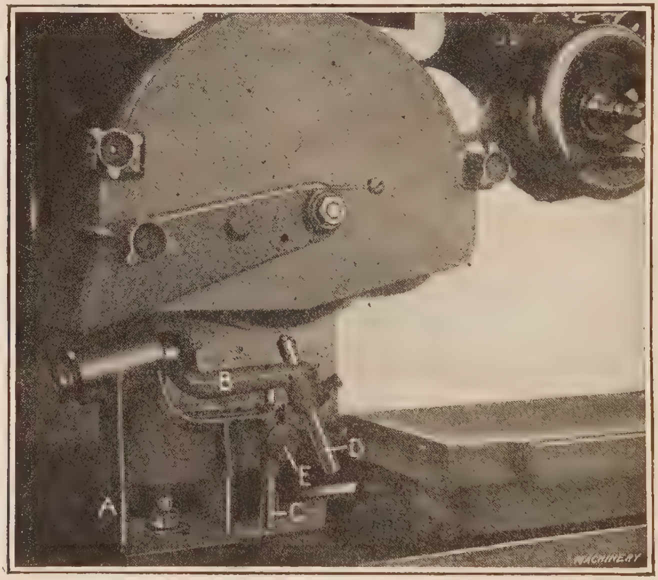


Fig. 11. Radius Wheel-truing Device for Surface Grinding Machine

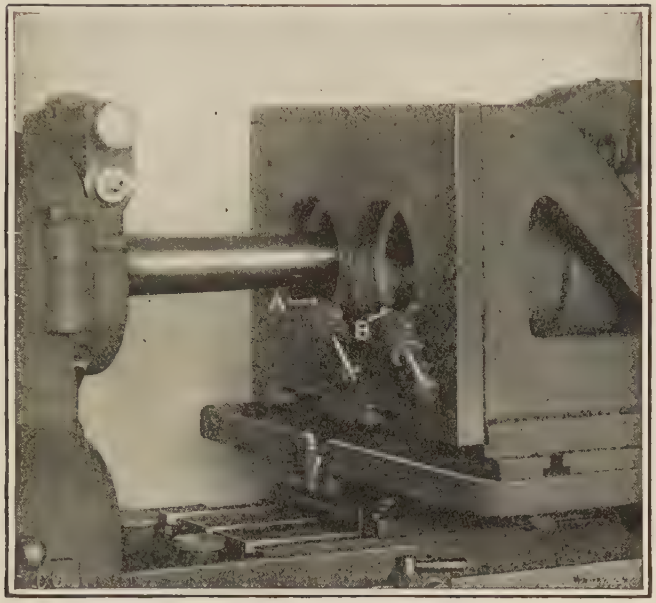


Fig. 12. Fixture equipped with Diamond Tools for Truing Wheel on Heald Cylinder Grinding Machine

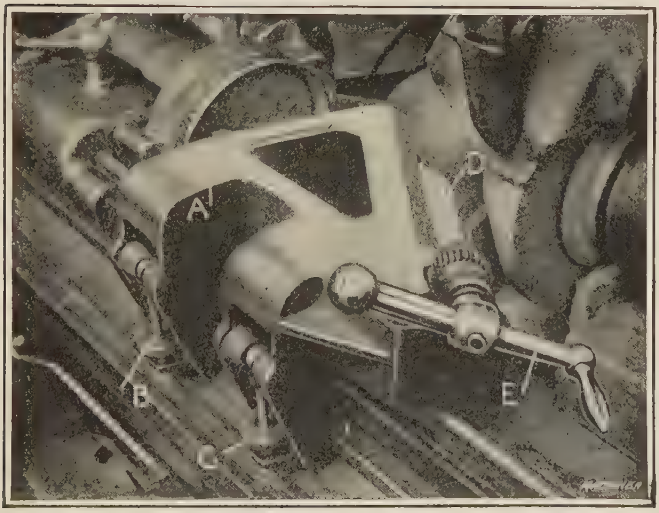


Fig. 13. Angular Wheel-truing Device for Cylindrical Grinding Machine

ened, and the wheelhead traversed, in order to true the wheel parallel with the axis of the wheel-spindle.

Wheel Truing on Cylinder Grinding Machines. — When grinding cylinders for automobile engines, etc., it is necessary that the grinding wheel be kept in good condition, which requires frequent truing of the wheel. The two small diamond tools shown at *A* and *B* in Fig. 12 do this work satisfactorily. The front of the work-holding fixture carries two brackets which hold split bushings that are acted upon by set-screws. Screwed into these bushings are the two threaded diamond holders carrying a diamond at their points. With the tools mounted in this way, it is possible to true the wheel quickly, after taking the roughing cuts from each cylinder bore, thereby obtaining a good surface on the wheel for finishing.

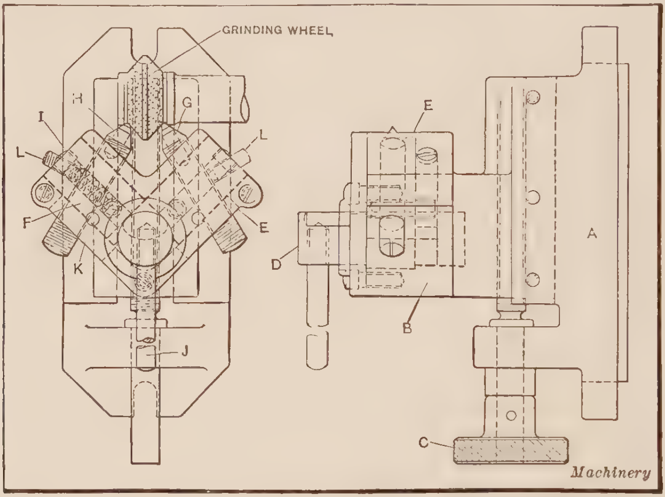


Fig. 14. Double-angle Wheel-truing Fixture for Internal Grinding Machine

Angular Wheel-truing Devices. — Fig. 13 shows an angular wheel-truing device for truing the wheel on a plain cylindrical grinding machine to a bevel shape, or, in this case, to an angle of 36 degrees with the axis of the grinding wheel. The fixture is of comparatively simple design. The bracket *A* is fastened to the table of the grinding machine by clamps *B* and *C*. Bracket *A* carries a slide *D* in which the diamond holder is mounted.

This slide is operated longitudinally by means of a rack and pinion, receiving motion from handle *E*. This fixture can only be used for truing the angular surface; for truing the straight portion on the wheel, an ordinary wheel-truing device is used.

A double-angle wheel-truing device, for use in forming a wheel for making a cone-shaped ball race, is shown in Fig. 14. The base *A* is machined to fit a bracket *B* that can be adjusted by screw *C*. The operating mechanism of this device includes an eccentric bolt *D* which passes down through block *B* and is prevented from pulling out by a pin fitting in a groove in the lower end. Opposite the eccentric portion of this pin are located two slides *E* and *F*, carrying the diamond holders *G* and *H*. The rear ends of these slides are curved slightly, to conform to the cam, and are kept back in contact with it by means of two coil springs *I*, only one of which is shown in the illustration.

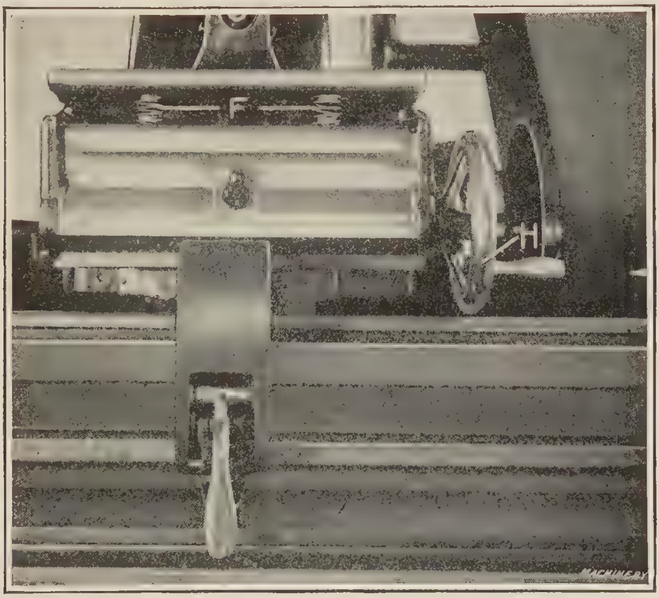


Fig. 15. Fixture for Forming Irregular Shapes on Face of Grinding Wheel

The method of operating the fixture is to swing handle *J* in one direction, say, to the left, thus forcing out the slide carrying diamond holder *G*, which travels along the angular face of the wheel until handle *J* strikes stop *K*. The handle is then swung in the opposite direction and the other diamond holder comes into play. Screw *C* is operated to bring both diamond holders into the correct working position relative to the wheel. The diamond holders, which are provided with a thread and are screwed into the slides, are set by means of a gage of the same shape and size as the work. They are then clamped in position by set-screws *L*.

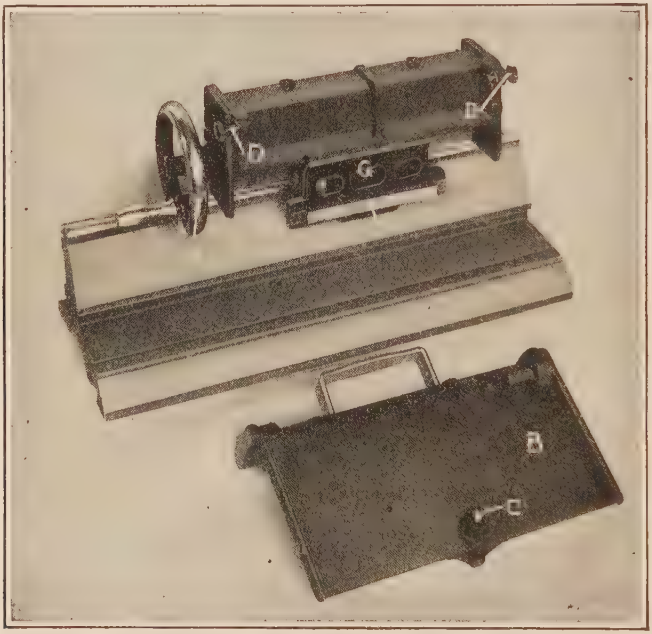


Fig. 16. Wheel-truing Device shown in Fig. 15 dismantled to show Construction

Truing Formed Grinding Wheels. — For some classes of work, it is necessary that a wide face wheel be trued to an irregular form. To do this, it is necessary to use a device in which the form is controlled by means of a cam, former plate, or other mechanism of a similar nature. Fig. 15 shows a truing attachment of this type applied to a Norton plain grinding machine, whereas, Fig. 16 shows it removed and partly dismantled. There is a former plate *A* (which, in this case, is plain), a diamond holder or plate *B*, and a diamond tool *C*. Plate *B* is held on pivots *D* and is kept in contact with the cam by means of coil springs *F*. Cam *A* is held in a carriage or slide *G* that is traversed laterally by means of a screw to which handwheel *H* is attached. By rotating this handwheel, the carriage carrying cam *A* is traversed and the face on the cam, which may be of any desired form, imparts an in-and-out movement to plate *B* carrying the diamond. The entire device is clamped on the table of the grinding machine.

Another attachment for truing formed wheels is shown in Fig. 17. It is clamped to the front of the grinding machine bed, and at the top of the bracket is fitted a slide *A*, operated by handwheel *B*. Upon the face of this slide, nearest the grinding wheel, is pivoted an angular arm *C* that supports the diamond *D* at its lower end. Under the end of the upper arm is a spiral spring that keeps the diamond normally back from the wheel. A plate former *E*, clamped to the bottom face of the bracket, is shaped to agree with the form to be given the wheel. Located at the lower extremity of the arm and behind the diamond is mounted a roll *F* that bears constantly against form *E*. When the diamond slide is reciprocated, by turning the handwheel, the diamond is made to traverse a path conforming with the cam that guides it.

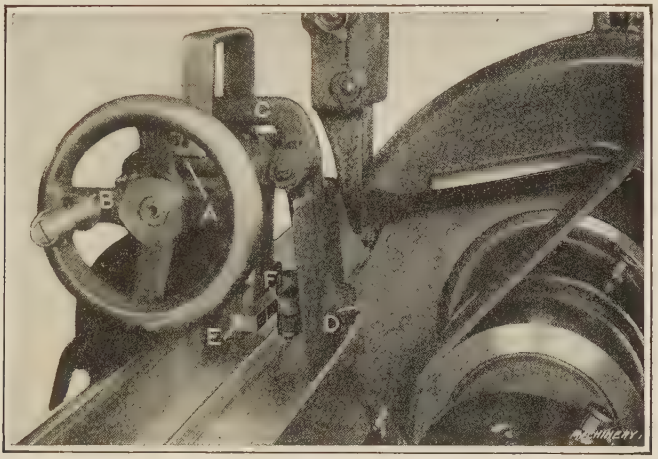


Fig. 17. Another Attachment for Truing Formed Wheels

Diamond Holder for Surface Grinder. — In applying a diamond holder to a wheel held on a surface grinder, the holder should, when possible, be held on the table under the wheel and not up at the side of the wheel in the same horizontal plane as the wheel-spindle. Holding the diamond-truing device on the table reduces the tendency to chatter, and it is much more easily applied. Fig. 18 shows a simple diamond holder for use on a Heald piston ring grinding machine. There is a plate *A* in which the diamond holder *B* is retained, plate *A* being held on the magnetic chuck. The diamond is used by traversing the wheel over it, the work-table remaining stationary.

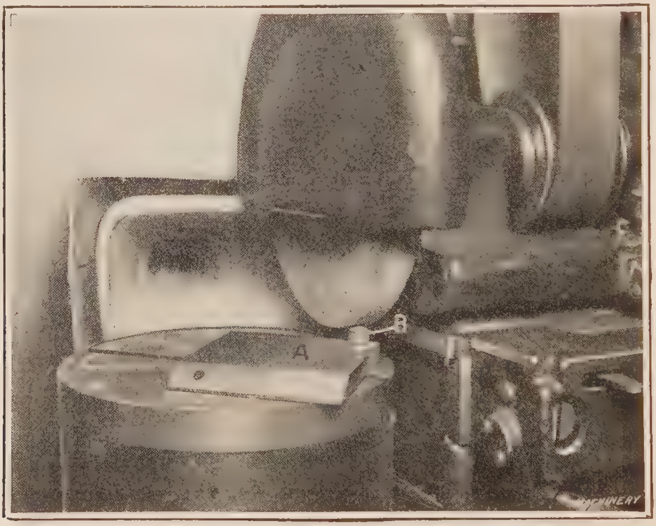


Fig. 18. Simple Form of Wheel-truing Device for Piston Ring Grinding Machine

Truing Attachment for Surface Grinder. — The wheel-truing device shown in Fig. 19 is held on the wheel guard or hood. Slide *A*, which holds diamond holder *B*, is adjusted up and down along the face of slide *C* by means of screw *D*. Slide *C*, in turn, is moved along the gibbed slide on bracket *E* by means of handle *F*. The screw to which handle *F* is attached is of coarse pitch, enabling slide *C* to be traversed rapidly. The vertical screw *D* is of fine pitch, enabling accurate adjustment of the diamond to be made. With this attachment, it is unnecessary to remove the wheel-truing device, in order to grind the work.

Wheel-truing Device for Crowning Pulleys. — The attachment shown in Fig. 20 is used chiefly for truing the face of a grinding wheel that is used for crowning pulleys by feeding straight in to the work. Bracket *A* is fastened to the grinding machine table by clamp handle *B*, and carries an adjustable slide *C* in which the diamond holder is mounted. Slide *C* is held on bracket *D* clamped to bracket *A* and is free to swivel

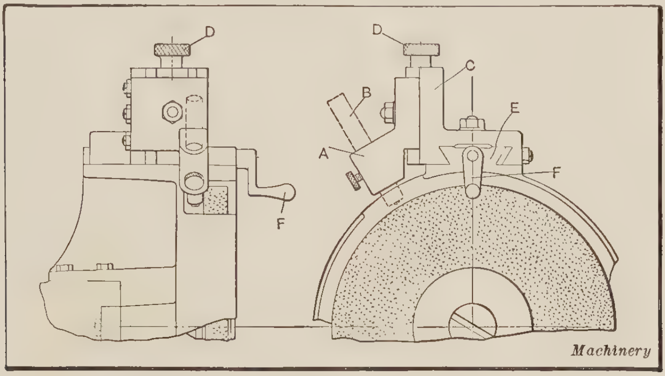


Fig. 19. Wheel-truing Attachment on Wilmarth and Morman Surface Grinding Machine

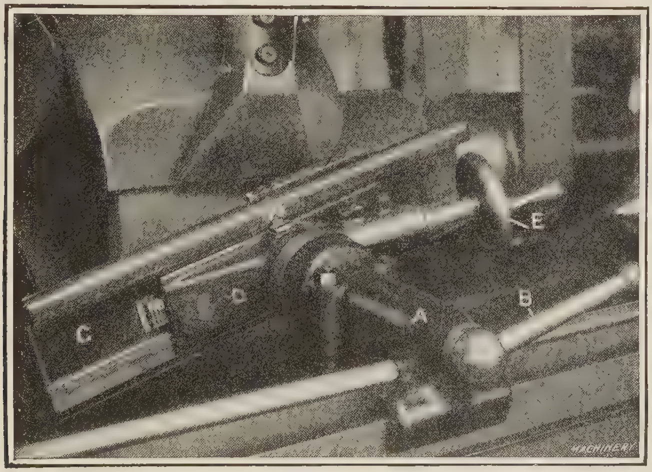


Fig. 20. Attachment for Truing Concave Wheel-face for Grinding Crowned Pulleys

when the clamping bolt is released. The boss on bracket *D* is graduated so that the required amount of inclination of the slide, in relation to the axis of the wheel-spindle, can be obtained.

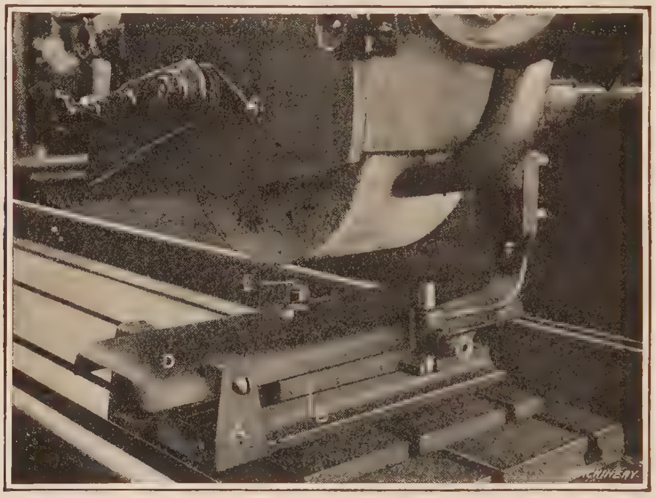


Fig. 21. Fixture for Truing Face of Wheel to Irregular Form

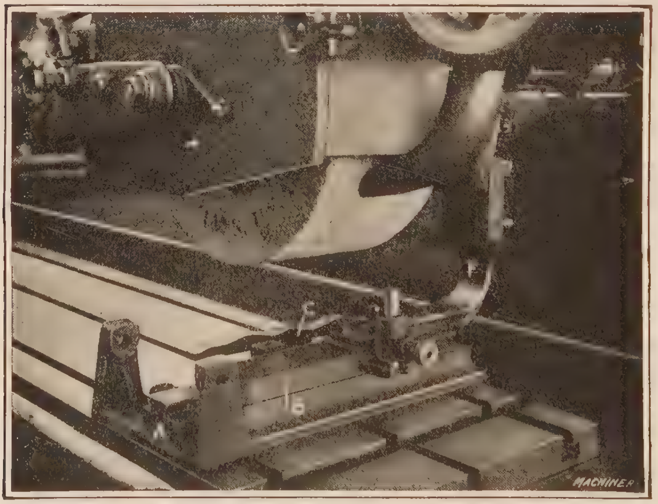


Fig. 22. Fixture illustrated in Fig. 21 partly dismantled

The degree to which the wheel-truing slide is tilted determines the amount of concavity on the wheel-face, which, of course, governs the height of the crown on the pulley. Slide *C*, carrying the diamond, is moved back and forth by means of a rack and pinion operated by handwheel *E*.

Truing Formed Wheel on Surface Grinder. — Figs. 21 and 22 show a wheel-truing device that is used on a Norton surface grinding machine for truing the face of the wheel either to straight or irregular form, depending on the shape of the guiding cam used. Bracket *A* is held to the table of the machine. On top of this bracket is fitted a slide *B* which carries cam *C*; this cam operates plate *D* carrying diamond holder *E*. Slide *B* is

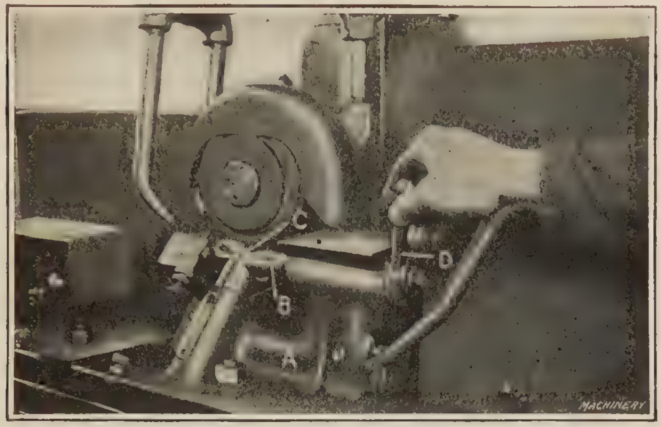


Fig. 23. Attachment for Truing Curved and Angular Surfaces on Wheel used for Grinding Spline Shafts

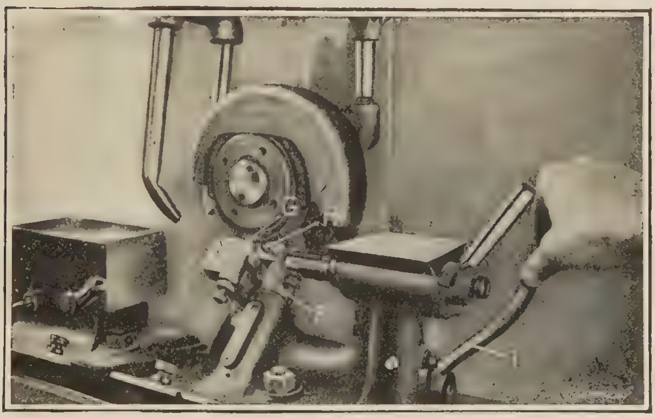


Fig. 24. Wheel-truing Device shown in Fig. 23 set for Truing Sides of Grinding Wheel

operated by arm *F* which is attached to the wheel slide and moves with it. As slide *B* is traversed, cam *C* moves plate *D* up and down, thus raising and lowering the diamond in accordance with the shape of the cam. By simply changing the shape of the cam, this same device can be used for truing the wheel to various shapes.

Truing Wheel for Grinding Spline Shafts. — An interesting attachment used on a Bath multiple key-shaft grinding machine, for truing both the curved and beveled surfaces of the grinding wheel, is shown in Figs. 23 and 24. This attachment consists of a bracket *A*, fastened to the grinding machine table, and carries three diamond holders, one of which is used for truing the radius, as shown in Fig. 23, and the other two for truing the bevel on the sides, as shown in Fig. 24. Referring to Fig. 23, it will be seen that the spindle *B* carries a diamond holder *C*, which is set to give the desired radius by means of an adjusting screw. Spindle *B* is then rotated by means of lever *D*, and, in this way, the curved surface on the face of the grinding wheel is formed.

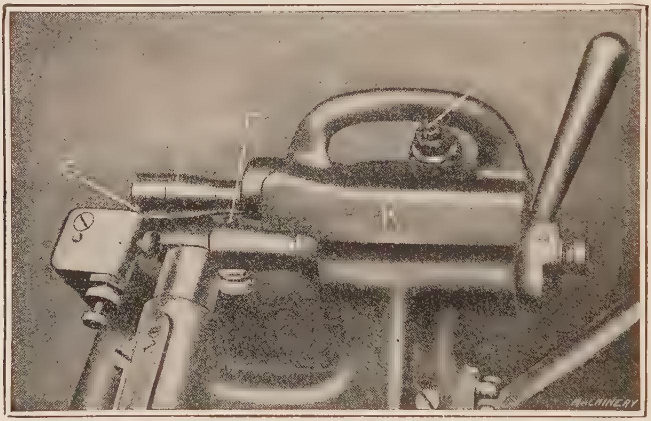


Fig. 25. Attachment used in Connection with Wheel-truing Device shown in Figs. 23 and 24 for setting the Diamond Tools

For truing the angular surfaces on the wheel, two separate holders *E* and *F* are used, as shown in Fig. 24. These holders carry separate diamond tools *G* and *H* which are adjusted by means of a screw and lock-nut. These two holders are operated independently and alternately by means of handle *I* and a spindle carrying a cam. The holders are kept in contact with the cam by means of springs, and as the handle is moved in opposite directions, it operates the diamond holders. In this way, both sides of the wheel are trued in proper relation to each other.

The device for setting these diamond tools is shown in Fig. 25. Part *K* fits over the dovetail slide on top of the fixture and is clamped in place by bolt *L*. A plug gage *M*, provided with two diameters, is used for setting the diamond points. Diamond holder *C* is so adjusted that the point is in contact with the smallest diameter of the plug, whereas, the diamond holder *G* (the one on the other side) is placed in contact with the largest diameter of the plug. With this device, it is possible to obtain a very accurate setting of the diamonds.

There is a large variety of devices and attachments used for truing grinding wheels for various purposes, but those referred to in the foregoing represent typical designs and illustrate principles of comparatively wide application. Practically every device shown can, with slight modifications, be adapted to a considerable range of work.

CHAPTER IX

METHODS OF HOLDING WORK FOR GRINDING

THE correct method of holding work for grinding is governed largely by the nature of the work, its shape, the type of machine used, and other requirements, such as accuracy, production, etc. The methods employed in different plants on various classes of work are so diversified that it is only possible to describe and illustrate a few of the more common types of work-holding devices. In designing a work-holding device for a part that is to be ground, there are a number of points which should be considered.

For the average line of work, the conditions that are met with may be summed up as follows:

1. Shape of work; whether hollow, provided with centers, or "blind" on one end.

2. Location of surface to be ground; whether concentric as in long, plain shafts, or eccentric as in crankshafts and camshafts.

3. Slenderness of such parts as bushings, sleeves, etc.

4. Relation of ground surfaces to previously finished parts.

5. Convenience of operation as regards accessibility for removing or clamping the work.

6. Accuracy and production required. Aside from the nature of the work, this last point is usually the most important.

Holding Work on Centers. — The common method of holding and driving work while grinding it externally, when centers are provided, is shown in Fig. 1; this is the well-known method used on plain or universal cylindrical grinding machines. The shape of the machine center is sometimes varied according to conditions. The common plain 60-degree center is shown at *A*, Fig. 2; the center at *B* is partially cut away to clear the wheel and permit work of small diameter to be ground. Another method of reducing the body of the center for holding small work is shown at *C*, whereas, a center for supporting tubing or work having a large hole in the end is illustrated at *D*. The center shown at *E* is used to support work not having a center but a pointed or conical end.

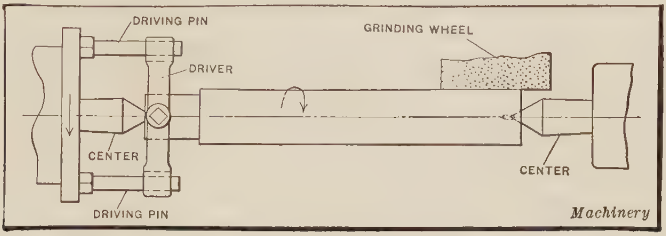


Fig. 1. Common Method of Holding and Driving Centered Work when Grinding Externally

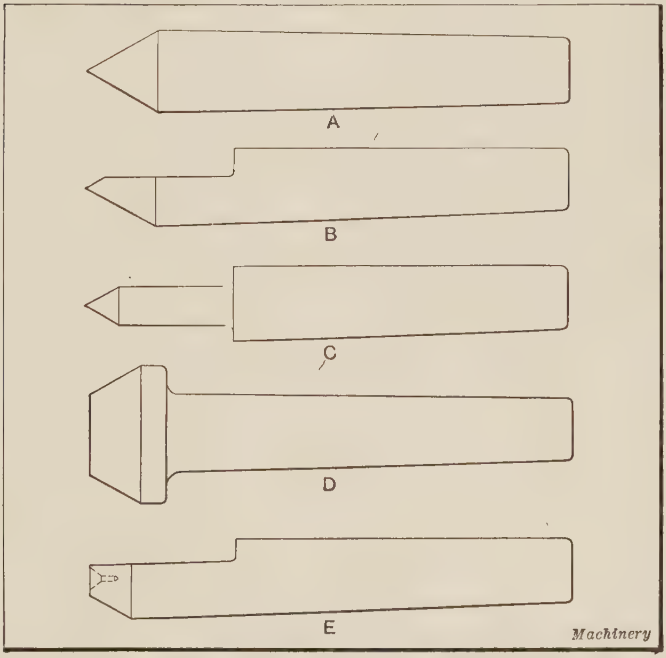


Fig. 2. Different Forms of Centers for Cylindrical Grinding Machines

When the work has a center in one end only, and a large hole in the other, like a gas engine piston, it can be held as shown in Fig. 3. A plate *A* is fitted into the hole in the open end of the piston and a pin *B* passes through the wrist-pin hole and rod *D*.

When the wrist-pin hole has been previously bored and reamed in alignment and at right-angles to the axis of the piston, the pin *B* should be a good fit in the wrist-pin hole, but, if the latter has not been finished in this way, previous to grinding, pin *B* should be a loose fit, as illustrated. The piston is held against plate *A* by nut *C* which draws pin *B* against the wrist-pin hole and clamps the piston rigidly. The arbor is driven by a pin *E* which engages the driving pin in the faceplate of the grinding machine.

Another method of holding work on centers is shown in Fig. 4. One end of the work is centered and the other slotted, and the requirements are that the axis of the shank or body of the work be at right angles to the center of the pin hole. In order to locate this part accurately, a close-fitting pin *A* is inserted into the hole. The headstock center *B* has a V-slot to engage pin *A* and is made to fit the slot in the work. This type of center, in addition to holding the work central, also drives it.

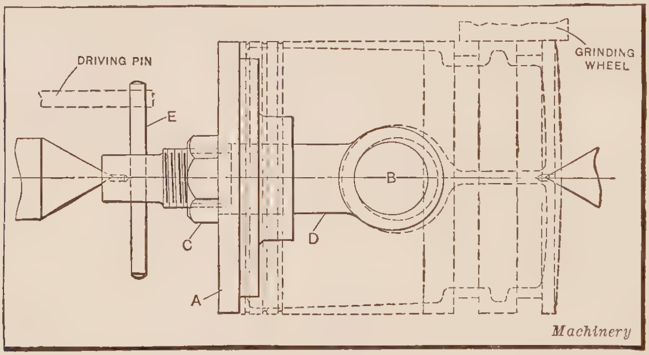


Fig. 3. Method of Holding a Gas Engine Piston for External Grinding

A method of holding a one-throw crankshaft, for grinding the crankpin, is shown in Fig. 5. Many fixtures have been designed for work of this class; the device illustrated is of very simple construction but not as effective as the fixtures ordinarily used where crankshaft grinding is done regularly (see Chapter X). The work is held by two blocks which are fitted to the ends of the crankshaft and retained by set-screws. As it is necessary to align the blocks with the crank before clamping, the ends are made square, so that they can rest on a surface plate; then the crankshaft and blocks are squared up from the surface plate with an ordinary machinist's square. Other work of an eccentric nature may be held in a similar manner, the type of fixture used depending on the exact form of the work.

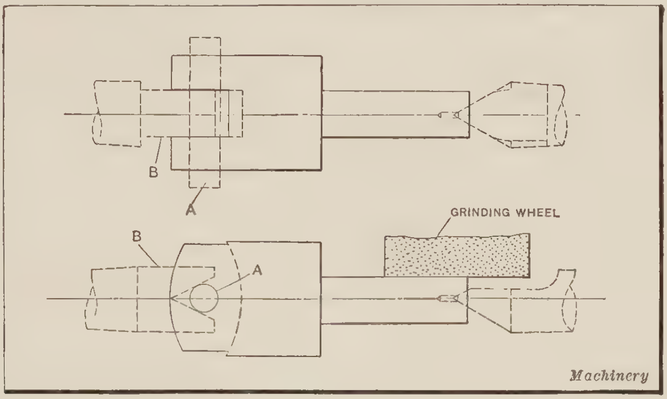


Fig. 4. Method of Holding a Part having a Slotted End

Holding Work on Solid Mandrels. — A common method of holding work on a mandrel is shown at *A* in Fig. 6; in this case, the part to be ground is an ordinary plain bushing. A bushing that is to be held in this way, especially if thin, should be clamped endwise while being ground internally, as explained in Chapter III (see paragraph, HOLDING WORK FOR INTERNAL GRINDING). Mandrels of this kind should never have the work driven tightly on them and they should have a taper of about from 0.002 to 0.005 inch to the inch. At *B* is shown a common method of holding a taper bushing.

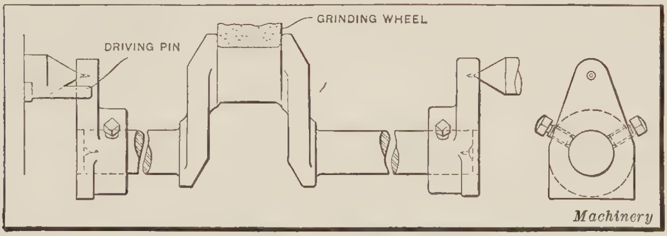


Fig. 5. Simple Method of Holding and Driving a One-throw Crankshaft when Grinding the Crankpin

Fig. 7 shows a simple but effective mandrel for holding a ball-race cup. This is a difficult piece to hold properly, and the method shown is very effective. The mandrel consists of a central stud *A*, hardened and ground, and threaded to receive the knurled bushing *B*. This bushing is also hardened and is ground internally as well as on those surfaces which come into contact with the ball-race cup. The cup is held in position by turning sleeve *B*, so that it forces the cup against split washer *C*, which is hardened and ground on the sides. The mandrel is driven by pin *D* and the driving pin on the faceplate of the machine.

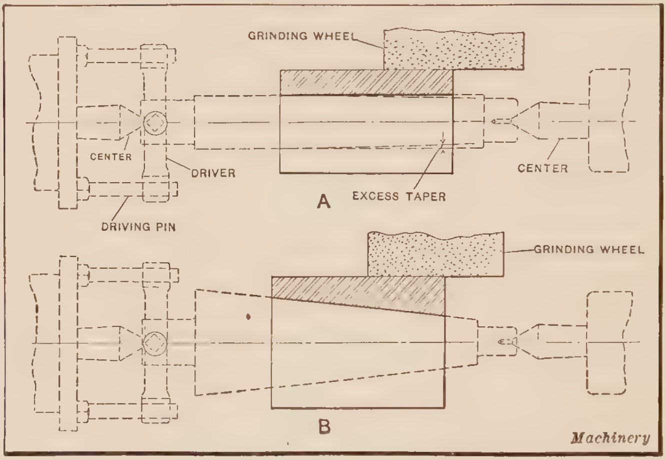


Fig. 6. Use of Solid Mandrels for Grinding Bushings

End-clamping Mandrels for Bushings. — The grinding of bushings having thin walls is sometimes quite difficult; if these have been hardened, the hole is usually distorted and cannot be depended upon as an accurate surface from which to locate the work for grinding the external diameter. The hollow piston pin shown on a special mandrel in Fig. 8 illustrates this point. This piston pin is made from Shelby tubing having a $\frac{5}{32}$-inch wall; it is carbonized 0.030 inch deep and hardened. In the carbonizing and hardening, the tubing is considerably distorted, and to place it on a solid mandrel, to grind the external diameter, would mean that it would only bear on the high points and would be distorted. The mandrel used for holding this pin has a central mandrel *A*, which carries two sleeves *B* and *C* as well as two cone-ended work supports *D* and *E*, these being backed up by open-wound springs *F* and *G*. The work is merely located by sleeves *D* and *E* and is clamped from the ends by sleeves *B*, *C*, and nut *H*.

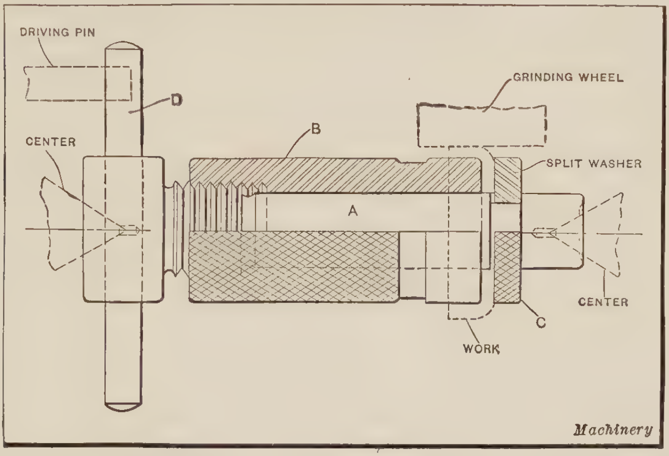


Fig. 7. Special Mandrel for Holding Ball Race Cup while Grinding External Diameter Concentric with Raceway and Square with Inside Face

Two or three of these mandrels are made up at one time, so that while one piece is being ground in the machine, the operator can be loading another. To insert the work on the mandrel, nut *H* is removed and sleeves *C* and *E* withdrawn; sleeve *E* has a pin fitting in a slot in sleeve *C*, so that the spring cannot force it off the mandrel when the sleeve is removed. The work is placed on the mandrel and is centered by the end of the stationary sleeve *D* as well as by pin I. Then sleeve *C* is re-

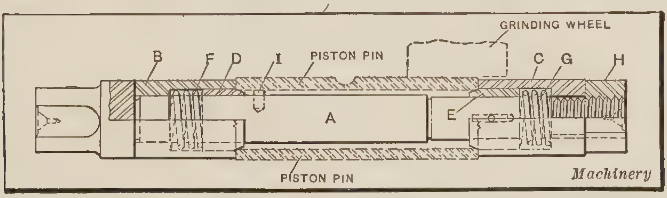


Fig. 8. End-clamping Mandrel for Holding a Piston Pin Without Distortion

placed and nut *H* tightened sufficiently to hold the work in position.

In Fig. 9 is shown another "floating" or end-clamping mandrel that differs slightly from the one previously described. This mandrel has a hardened and ground center bar *A* and a bushing cup *B* is pinned to it. Cup *B* is counterbored to receive the spring-controlled cone-sleeve *C* that is held in place by fillister-head screws *E*. The bushing is centered by cone-sleeve *C*, and sleeve *F* holds it tightly against the bushing cup *B*.

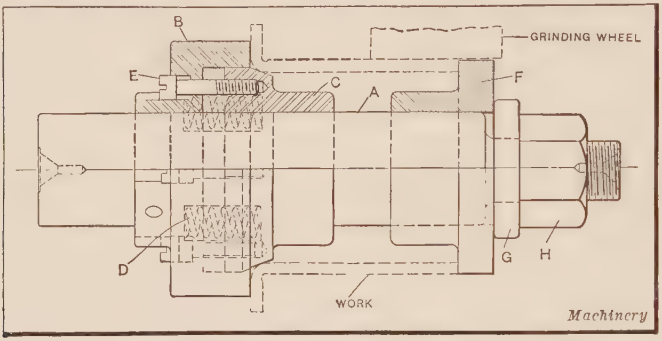


Fig. 9. Another End-clamping Mandrel for Holding a Bushing

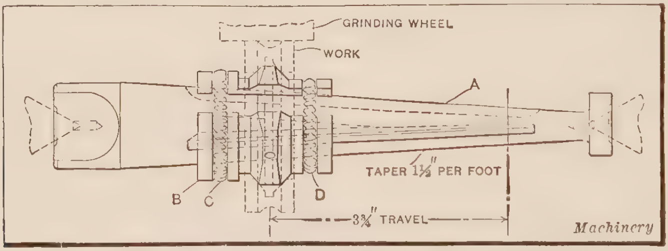


Fig. 10. Expanding Mandrel for Holding an Outer Ball Race while Grinding the External Diameter

The mandrel is provided with a slotted washer *G* and nut *H*. To remove the work, nut *H* is released and washer *G* withdrawn, enabling sleeve *F* and the work to be removed.

Expanding Type of Mandrel. — When grinding a ball bearing race externally, it should be located from the inner bearing surface for the balls. The expanding mandrel, therefore, is the only type to use. Fig. 10 shows a special mandrel designed for this purpose. The tapered rod *A* has three segment work supports *B* which are prevented from turning on the arbor by pins that engage slots in the arbor. These segments are held together by two "bracelet" coil springs *C* and *D* that completely surround them. To place the work on the mandrel, the three segments are drawn down to the smallest end, the work slipped over them, and then the segments are pushed back, causing them to expand and grip the work.

An important point in connection with this mandrel is the amount of taper given to it. The first mandrel that was used had an included taper of 15 degrees — about $3\frac{1}{8}$ inches to the foot. It was found when this mandrel was used that it was impossible to hold the work square with the axis of the mandrel. Because of the steep taper, a slight tilting action was given to the segments, making it impossible to hold the work accurately. Another mandrel was made, having a taper of $1\frac{1}{2}$ inch to the foot, which was found to work satisfactorily; it held the work much more rigidly and accurately than the former mandrel.

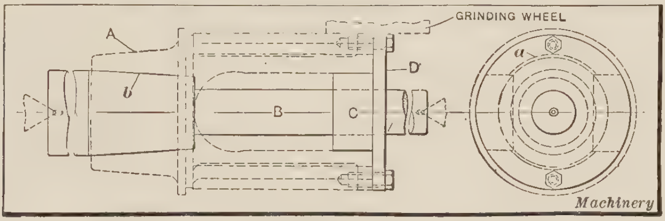


Fig. 11. Mandrel for Holding a Transmission Yoke

Mandrel for a Transmission Yoke. — The transmission yoke *A*, Fig. 11, is split or slotted at one end and the other end has a tapered hole. The requirements are that the external diameter be ground true with the tapered hole. The bearing surface *a* and tapered hole *b* are ground prior to this operation. This gives two points from which the work can be accurately located for grinding the external diameter. The mandrel has a hardened and ground rod *B* and a flattened bushing *C* ground to fit accurately in the previously ground bearing *a*. This bushing supports the yoke. In order to prevent the work from springing outward, a ring *D* is clamped to the end by bolts, which fit into previously tapped holes. This prevents any outward or inward springing of the yoke while it is being ground. The work is held for driving by the tapered portion on the mandrel which fits into the tapered hole *b*.

Special Fixture for Conical Work. — The part *A* to be ground (see Fig. 12) is a cone for a fan shaft and the operation consists in grinding the conical surface. The work-holding fixture is an old type Landis center grinder which has been changed to suit the requirements. The regular spindle was removed and substituted by a special draw-in spindle *E* operated, for holding the work, by an open-wound spring *B*. The front end of the spindle is slotted and carries a removable split washer. To remove the work from the fixture, lever *C*, fulcrumed in special bracket *D*, is forced forward carrying with it spindle *E* and compressing spring *B*, thus allowing the washer and work to be removed. Previous to the use of this fixture, the cones were ground in a special machine fitted up for the purpose. The fixture was then used and production was increased from 800 to 1200 pieces in nine hours.

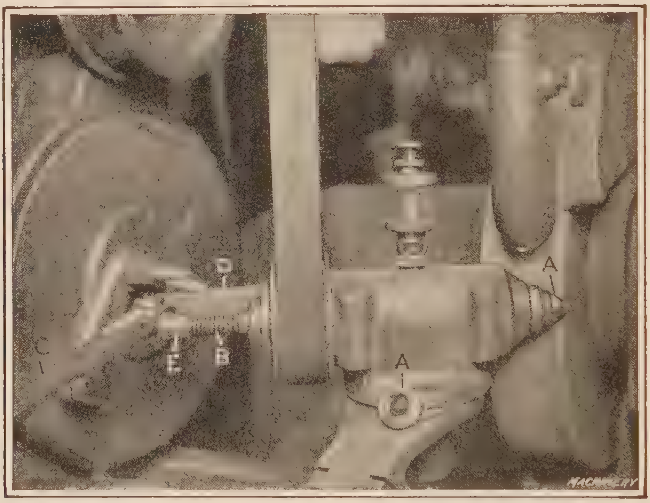


Fig. 12. Special Fixture for Holding a Conical-shaped Part

Work-holding Devices for Internal Grinding. — A common method of holding work to grind it internally, especially if the part to be ground is cylindrical in shape, is to grip it in a four-

or three-jaw chuck, as shown at *A* and *B* in Fig. 13. The jaws of the chuck are sometimes formed to suit the shape of the work, and are generally ground after the chuck is placed on the machine, to get the required accuracy. The four-jaw chuck is not as frequently used as the three-jaw chuck, because three points of support, especially for rough surfaces, is better than four. For holding thin wall bushings, the ordinary chuck is not recommended, because of the liability of springing the work out of shape in clamping.

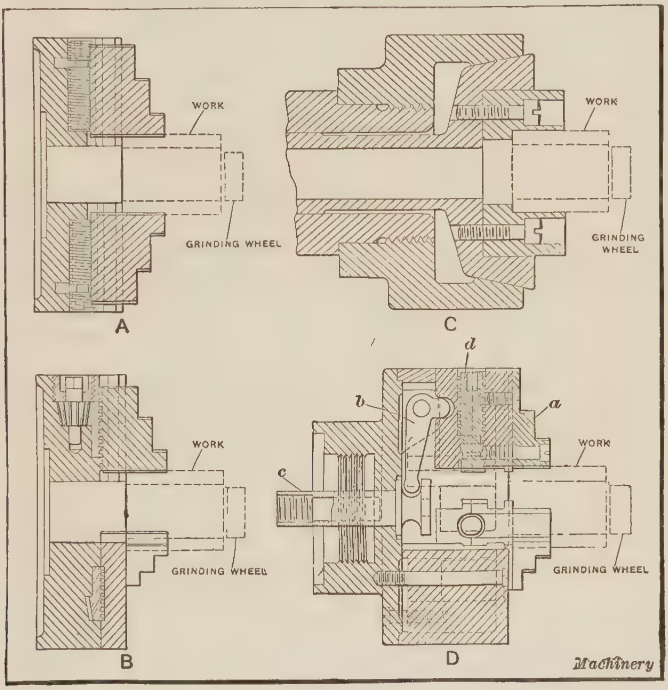


Fig. 13. Types of Chucks Commonly used on Internal Grinding Machines

For holding comparatively small work, the draw-in type of collet shown at *C* is used. This is limited, to a certain extent, to the holding of plain work, although, with slight modifications, this type of chuck may be equipped with segment-shaped removable clamping jaws. Another method of holding work of the bushing type is shown at *D*. This is an air-operated chuck.

The jaws *a* are operated through levers *b* which receive the necessary movement from plunger *c* connecting with the air cylinder. Jaws *a* can be adjusted independently by screws *d* to cover a considerable range of diameter. Air chucks can be used successfully on plain work that is stiff enough to stand the necessary clamping pressure without being sprung out of shape. One advantage of the air chuck over other mechanical gripping devices is that the pressure is constant.

End-clamping Chucks. — The external diameter of the thin bushing *A*, Fig. 14, is ground first by using a mandrel of the type shown in Fig. 9; then the work is held for grinding the internal diameter in a chuck of the type shown in Fig. 14 to prevent distortion. The bushing is slipped into a close fitting hole *B*. The body of the chuck is fastened to the faceplate *C* which is screwed onto the nose of the internal grinding machine spindle. The other members of the fixture consist of two toe clamps *D*, draw-bar *E*, and yoke *F*. Draw-bar *E* passes completely through the machine spindle and, being attached to yoke *F*, operates the toe clamps *D* that hold the work in place. None of the parts extend so as to interfere with the operation of the chuck or to cause accidents. In order to remove or replace the work in the fixture, the draw-bar is first released, then the toe clamps are swung away from the stop-pins *G*, the finished work removed, a rough piece inserted, after which the toe clamps are swung back to the stop-pins and the draw-bar tightened.

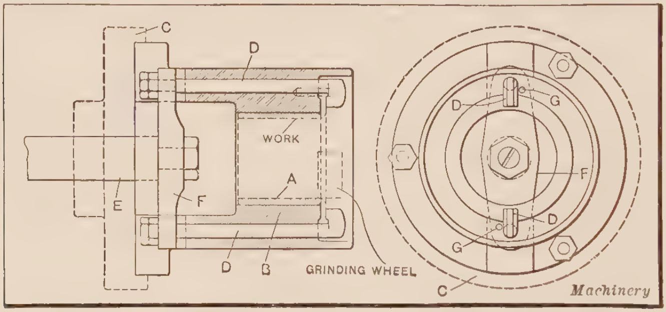


Fig. 14. Special End-clamping Chuck for Holding a Thin Wall Bushing while Grinding Hole

The drive shaft yoke, shown in Fig. 15, is another example of work that it is difficult to hold without distortion due to clamping. Yoke *A* has previously been ground on the outside while held on an arbor similar to that shown in Fig. 11; for grinding the internal diameter, it is held in a close fitting end-clamping chuck which does not exert pressure on the external diameter. The chuck consists of casting *B* screwed onto the nose of the machine spindle and carrying two toe clamps *C* tied together by yoke *D* and operated by draw-in bolt *E* passing through the spindle of the machine. In order to protect the workman, brass guard *F* is fitted over the chuck, so that the nuts on the ends of the toe clamps are not exposed. The forward end of this chuck is ground true with the machine spindle and to a good fit for the external ground surface on the work; the latter is held rigidly without subjecting it to any objectionable clamping strains.

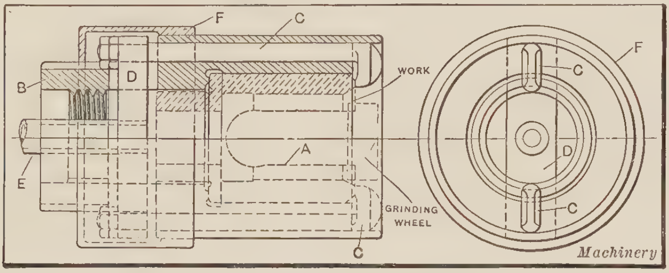


Fig. 15. Another End-clamping Chuck

Methods of Chucking Gears for Grinding. — The problem of holding gears accurately is a difficult one, especially if they have been hardened. The chief trouble is experienced in making provision for possible inaccuracies that are caused by warping in hardening. The following methods are in commercial use:

1. Holding the gear by the outside diameter or tops of the teeth.

2. Using rolls between the teeth — sometimes called the "pitch-line control method."

3. Using jaws of special shape which make contact with the gear at the bottom of the tooth spaces — a method known as "root control."

The first method cannot be used with success when the gears are to run at high speeds, because of the possible lack of concentricity between the hole and the outer surfaces of the teeth. The second method, while requiring the use of a more expensive chuck, is much more satisfactory than the first, provided the spacing of the teeth has not been affected by hardening, and the rolls are uniform in diameter and are supported by a truly concentric surface. A slight variation in the width of the tooth spaces, however, makes a considerable difference in the relative positions of the rolls, owing to the acute angle made by the tooth surfaces near the pitch-line where the rolls bear. This has been considered, by some manufacturers, a serious objection to this method. For the average line of work, the third method is recommended. The jaws of the chuck engage the bottom of the tooth spaces, so that inaccuracies of spacing, due to hardening the teeth, do not affect the accurate holding of the gear; furthermore, it is a very simple matter to maintain the accuracy of the jaws by simply truing the contact points whenever necessary. This does away with the continual truing of each gear. In the following examples will be shown different methods of holding both spur and bevel gears.

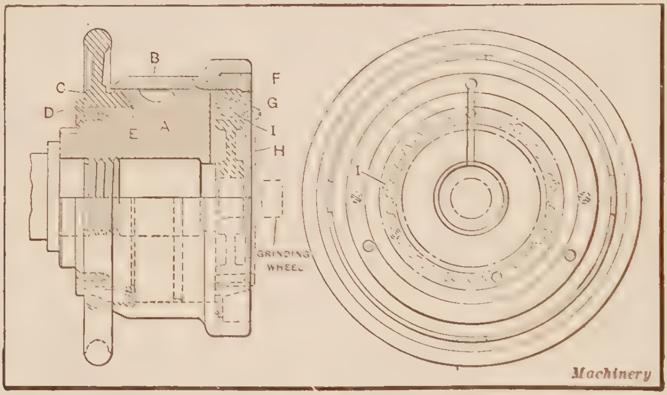


Fig. 16. Pitch-line Control Type of Chuck for Holding Spur Gears

Chucks for Holding Spur Gears. — When grinding the holes in spur gears, it is essential that the hole be true and concentric with the pitch circle of the gear teeth. One type of chuck designed to locate a gear with reference to the pitch circle is shown in Fig. 16. The fixture, which is screwed onto the spindle of a Heald internal grinding machine, has a cast-iron body *A* and a brass clamping sleeve *B*. Sleeve *B* is keyed to body *A* so that it can be drawn back and forth. This sleeve is operated by means of handwheel *C* having a projection which is threaded into sleeve *B*. The handwheel is held on the chuck by means of brass retaining ring *D*, and in order to eliminate friction, ball bearing *E* is interposed between the chuck and the handwheel. Sleeve *B* carries the tapered, cast-iron filler ring *F* that is held to it by means of fillister-head screws. This operates the hardened steel, split clamping ring *G*, inside of which is located retaining ring *H* carrying nine rolls *I*. These rolls *I* grip the gear teeth at the pitch circle. As handwheel *C* is operated, it draws in split sleeve *G*, closing the pins down on the teeth, thus holding the gear rigidly and accurately in position while the hole is being ground. Parts *F*, *G*, *H*, and *I* have to be made special for each size of gear handled.

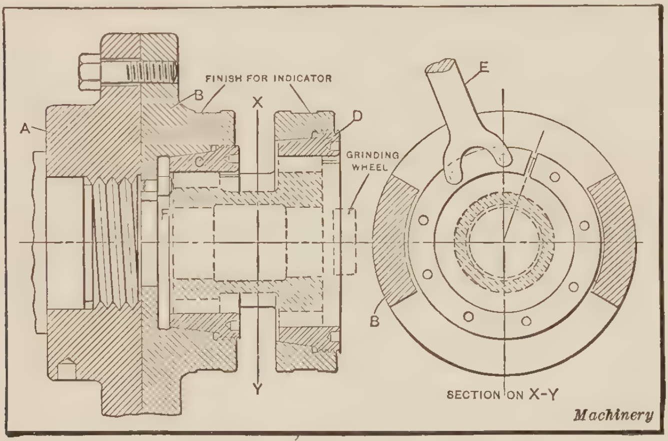


Fig. 17. Chuck for Holding a Double Spur Gear

An interesting chuck for holding a double spur gear is shown in Fig. 17. The construction of this chuck differs from the one previously described, chiefly in the method of clamping. A special faceplate *A* is screwed onto the nose of the spindle, to which is clamped the chuck housing *B*. Instead of locating the work from the pitch circle, the gears are held by the external diameters by cone-shaped split bushings *C* and *D*, which are tightened by means of the spanner wrench *E*. In order to get at the rear cone *C* with the wrench, the fixture is cut away, as illustrated. The end of the gear rests against hardened steel pin *F*. This method of holding a spur gear cannot be considered as accurate as holding it from the pitch circle, but where the gear has been carefully made, fairly accurate results can be secured. When the chuck is replaced on the machine, it is trued up with an indicator, the finished surfaces indicated being provided for this purpose.

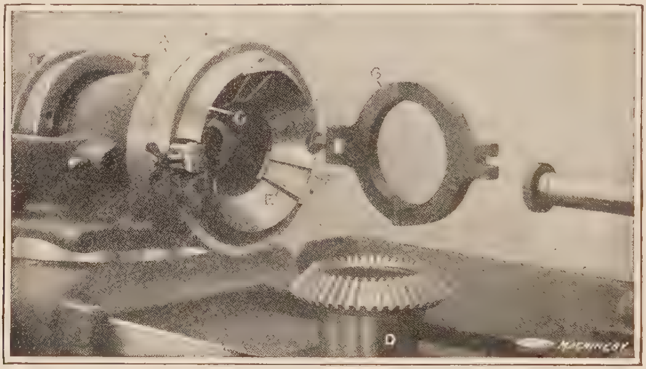


Fig. 18. Chuck for Holding Bevel Gears

Holding Bevel Gears for Grinding. — There is a diversity of opinion among users of grinding machines regarding the most desirable method of holding bevel gears and pinions for grinding. A device which has proved successful in one shop is not always regarded favorably in another. One important point about which a difference of opinion exists is the shape of the rolls used in chucks of the pitch-line control type. Some gear manufacturers claim that cylindrical rolls are just as satisfactory as tapered rolls. The Heald Machine Co. has given the problem of chucking gears for grinding considerable study and has designed several types of chucks, which will be described.

It is the experience of this company that the rolls for chucking bevel gears should be tapering, because they make contact with curved surfaces, the elements of which converge at a common vanishing point. This company has also found that gear manufacturers using cylindrical rolls have used them exclusively on gears having a face width that is small in proportion to the diameter of the gear, as, for example, ring gears used in automobile transmissions. In such cases, the error is not very pronounced, but on miter gears, especially when the face width is from one-quarter to one-fifth the gear diameter, there is a decided tendency for the gear to rock on a cylindrical roll at the center of the face of the gear tooth.

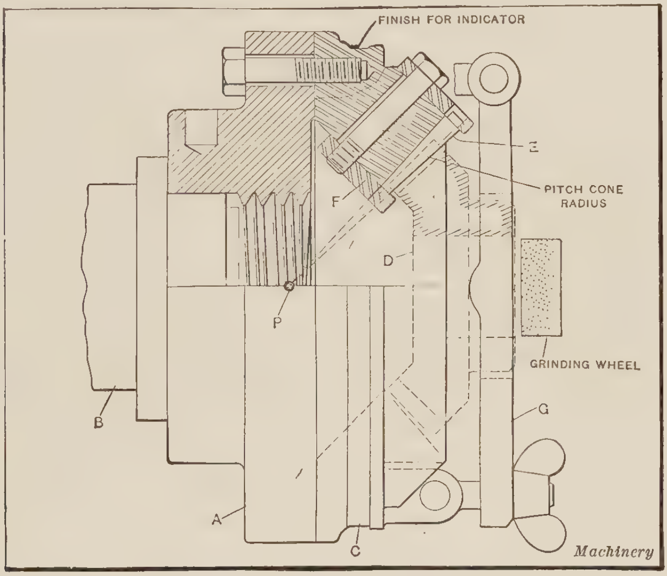


Fig. 19. Detailed View of Bevel Gear Chuck illustrated in Fig. 18

A satisfactory method of calculating the diameter and taper on the roll is to make the diameter at the large end sufficient to bring the surface of the roll about $\frac{1}{16}$ inch above the outside diameter of the gear teeth. The taper on the roll should be such as would cause it, if extended, to converge at the apex *P* of the pitch cone, as shown in Fig. 19. In making the rolls, the taper can be tested by inserting the rolls between the teeth on opposite sides of the gear, thus forming a temporary gage. The best method of holding the rolls, after they have been properly made, will be considered in the following in connection with various designs.

One type of chuck for holding bevel pinions is shown in Figs. 18 and 19. Fig. 18 shows the chuck in use on a Heald internal grinding machine. The gear is held by three sets of tapered rolls arranged in pairs. The faceplate *A* is screwed onto the grinding machine spindle *B*. Secured to faceplate *A* by screws, as shown, is a second plate *C* recessed to a suitable angle to receive gear *D* and rolls *E*. The rolls are retained in triangular-shaped plates *F* by cap-screws that hold the plates and rolls firmly to the plate *C* and also prevent dirt from getting under the rolls. The rolls are held so as to permit a slight movement, in order that they can adjust themselves with relation to the gear teeth. The gear *D* is held in place by a yoke *G* and a thumb-screw. This yoke exerts a pressure in a line parallel with the axis of the gear and assists in forcing the gear back to a concentric location.

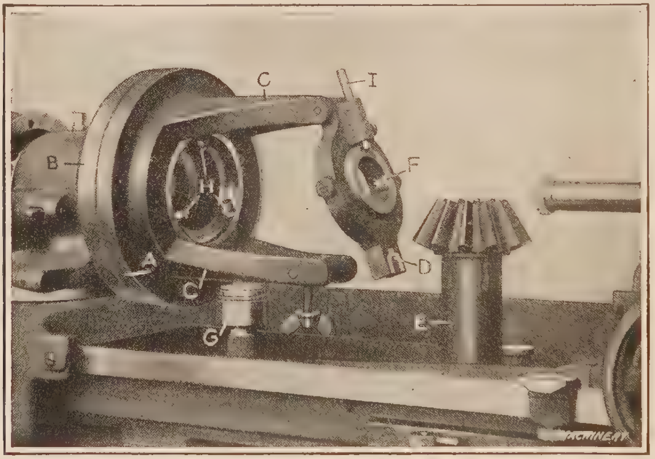


Fig. 20. Chuck for Holding a Long-shank Bevel Gear

Another type of chuck for holding a bevel pinion provided with a long shank or stem is shown in Fig. 20. In this case, the fixture *A*, which is fastened to faceplate *B*, has extension arms *C* that carry the clamping strap *D*. Gear *E* is $8\frac{11}{64}$ inches long, over-all, and the hole ground is $6\frac{1}{8}$ inches long by $2\frac{3}{8}$ inches in diameter. The clamping strap *D* carries bushing *F* in which the centering plug *G* fits to locate the shank of the pinion when it is being clamped in position. The gear is centered at the inner end from the pitch-line of the teeth by means of three balls *H* held in place by screws. The inner end of bushing *F* is chamfered to properly center the shank of the gear. In connection with this fixture, there is a device for truing the internal grinding wheel. The diamond holder *I* is held in a projection on the clamping plate *D* by a knurled-head screw. In truing the wheel, the work-spindle is stopped, the diamond brought down into contact with the wheel, and then the wheel slide is traversed back and forth until the wheel has been trued.

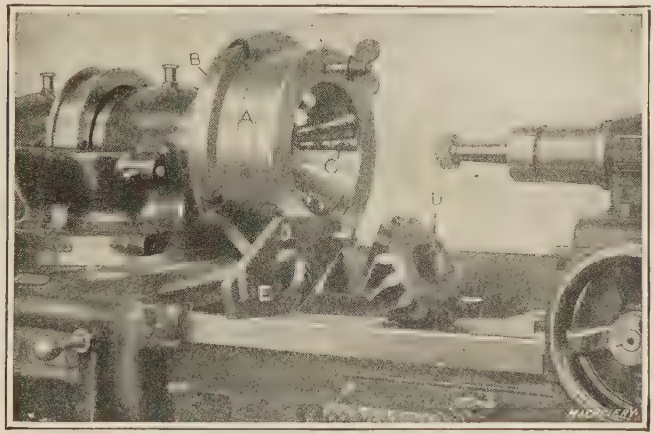


Fig. 21. Another Design of Chuck for Holding Bevel Gears

The chuck shown in Fig. 21 illustrates another method of locating and holding bevel pinions for grinding. This chuck is somewhat like the one shown in Figs. 18 and 19, although the tapered pins, for locating the pinion from the pitch circle of the teeth, are arranged differently. In this case, six tapered pins *C* are held in chuck *A* by screws. This method of fastening the rolls can be used, in this case, because of the coarse pitch of the gear teeth. There are six rolls but three would have been sufficient. The gear *D* is held in place by clamping strap *E* which carries two hardened pins that come into contact with the rear face of the gear.

When the bevel pinion to be ground is of comparatively small size, the Heald standard type of draw-in collet, shown in Fig. 22, can be used. The cast-iron cap *A* is screwed onto the nose of the machine spindle and receives the tapered ring *B*. The draw-in rod is screwed into a flange-shaped draw-bar *D* that is pinned to ring *B*, as shown; the latter is prevented from

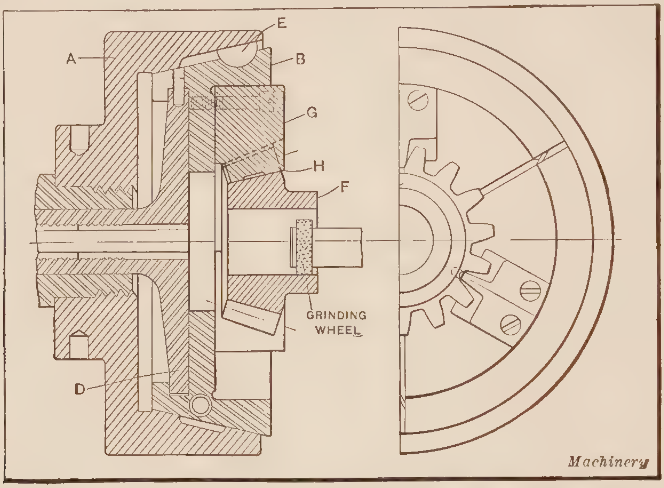


Fig. 22. "Draw-in" Collet for Holding Small Bevel Pinions by Means of Jaws which engage Bottoms of Tooth Spaces

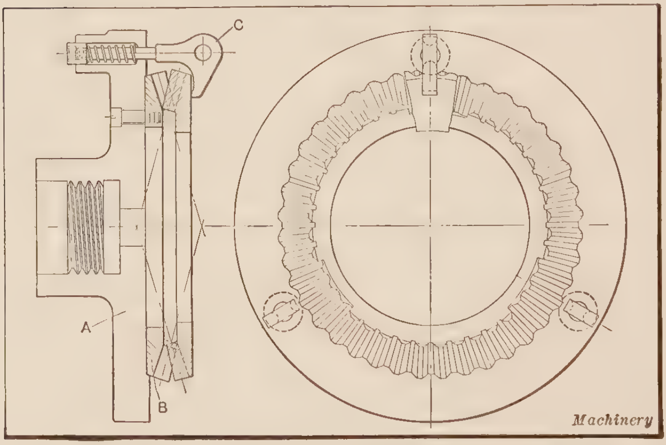


Fig. 23. Fixture having a Master Gear against which Bevel Ring Gears are Clamped

turning independently of cap *A* by a Woodruff key *E*. The gear *F* is held in place by three jaws *G*, fastened to ring *B* by screws, as shown. Jaws *G* are provided with small projections which extend over the outside of the gear, as shown at *H*, and prevent it from sliding out as the jaws are closed; hence, by simply opening and closing the jaws, the gear is clamped and released, without the aid of straps or yokes. An objection to this device is that if the teeth of the jaws do not have an even bearing on the bottom of the tooth spaces, the gear may not be held accurately.

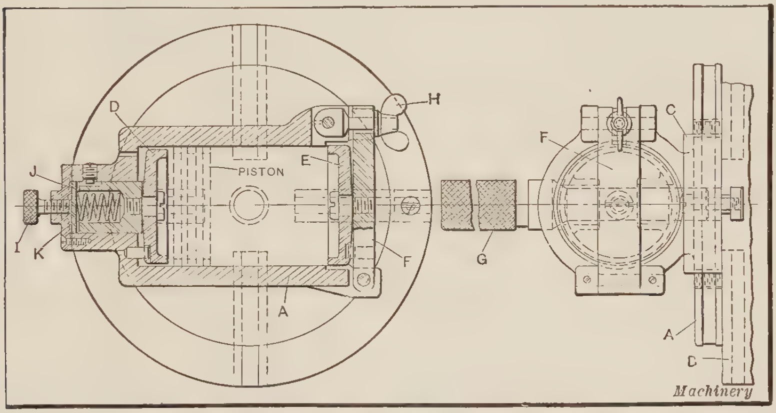


Fig. 24. Fixture for Holding Gas Engine Pistons while Grinding Wrist-pin Holes

One of the many fixtures used by automobile manufacturers for holding bevel ring gears while grinding the hole and the back face, when necessary, is shown in Fig. 23. Faceplate *A* is recessed to receive ring gear *B* of the same size and shape as the one to be ground. About three-quarters of the inner points of the teeth on this ring gear, which is left soft, are cut away, so as to leave three places containing three or four teeth each. The gear to be ground is clamped against this "gear chuck" by three toe clamps *C*, as illustrated. This device is self-centering, it only being necessary to place the gear so that the teeth will fit those teeth on the other gear which have not been cut away. The gear teeth that are in mesh also form a positive drive, and the holding mechanism simply keeps the gear in contact with the master gear or chuck.

Fixture for Gas Engine Pistons. — The wrist-pin holes in the pistons used in the H. H. Franklin Mfg. Co.'s automobile motors are provided with bronze bushings which are ground true after they have been forced in. The grinding is done in a Heald internal grinding machine provided with the special fixture shown in Fig. 24. The fixture proper *A* is fastened to the faceplate *B* located on the machine spindle by two clamping blocks *C*, only one of which is shown. These blocks are adjusted so that the wrist-pin hole of the piston is in alignment with the axis of the work-spindle. The hole in part *A* is ground accurately and is a good fit for the external diameter of the piston. Located at the bottom of this hole is a spring-operated plate *D* that holds the piston up against the top plate *E* fastened to the swinging clamping plate *F*.

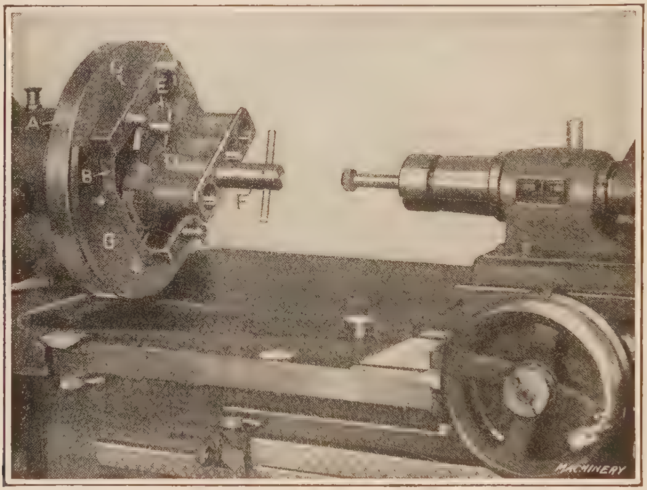
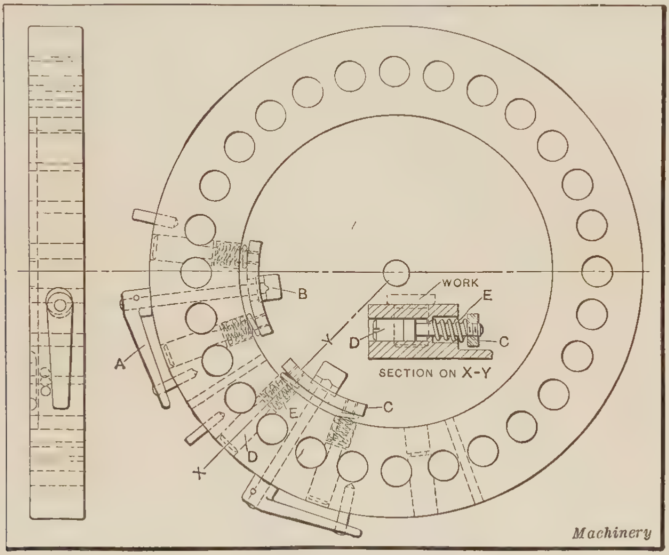


Fig. 25. Fixture for Holding a Four-bore Air Pump Cylinder

The method of locating the piston in the fixture is as follows: After the piston is put in, plug gage *G* is used to locate it from the previously reamed hole in the bushing. Clamping arm *F* is then swung down and thumb-nut *H* on the swinging bolt tightened. Should the spring pressure on the bottom plate not be sufficient, screw *I* is adjusted; this screw bears against plate *J*, which forms a backing-up member for the spring *K* that operates the sleeve carrying plate *D*. When the piston is properly clamped, the plug gage is removed and the grinding is done. The wrist-pin hole is located with reference to the open end of the piston. The chief requirement is to grind the hole accurately at right angles to the axis of the piston, and this fixture satisfactorily solves the problem.

Indexing Work-holding Fixture. — Fig. 25 shows an indexing work-holding fixture applied to a Heald internal grinding machine. The work being ground is an air pump cylinder in which four holes, $1\frac{1}{4}$ inch long by $\frac{3}{4}$ inch in diameter, must be ground. The slide *B* is held in place on the faceplate *A* by two guide-bars *C*. The pump cylinder casting *D* is held to the sliding or adjustable member *B* by clamps *E* and clamping screws. To locate each hole in line with the work-spindle, clamps *E* are released and slide *B* moved along until plug *F*, which is previously placed in the hole it is intended to grind, locates the casting properly by fitting in an aligning hole in the fixture.



Machinery

Fig. 26. Fixture for Holding Twenty-eight Bushings on a Rotary Surface Grinder

The fixture is counterbalanced by means of plate *G*; in order to keep as perfect a balance as possible, the casting is reversed end for end, after grinding two holes.

Fixture for Rotary Surface Grinder. — A fixture for holding sleeves while grinding the tops of the flanges in a rotary surface grinder is shown in Fig. 26. This fixture is clamped to the table of the machine and carries twenty-eight bushings which are ground at one time. The method of holding the bushings is shown diagrammatically in the center of the illustration. The clamping is done by levers *A* fastened to clamping bolts *B* which pass through the rim of the fixture and operate plates *C* to which the clamping members proper are attached. When clamping levers *A* are pushed down, cam surfaces come into contact with hardened cams held in plates *C*. Two bushings are clamped by each pin *D*; these pins fit in counterbored recesses in the fixture and are kept out from contact with the sleeves by means of coil springs *E*. This mechanism is very effective in clamping the work and can be quickly operated.

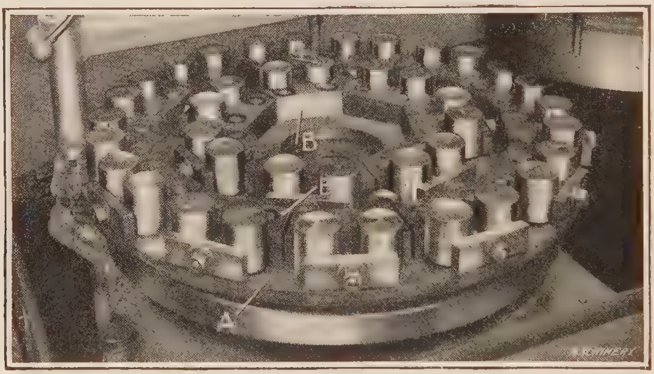


Fig. 27. Fixture for Holding Roller Bearing Rolls on a Vertical Surface Grinder

Fixture for Roller Bearing Rolls. — Many interesting fixtures have been devised for holding work on the vertical surface grinder, to act as an auxiliary holding device in connection with the magnetic chuck. One of these devices, used on the Blanchard machine for holding roller bearing rolls, is shown in Fig. 27. There is a base *A* to which are clamped two rows of segment blocks *B*. The rolls, both ends of which are to be ground, are clamped in V-shaped recesses in the sides of the blocks by the clamps shown, each clamp holding two rolls in place. Two fixtures of this type are provided, so that when the machine is grinding one end of a lot of forty rolls, the other fixture is being loaded, thus keeping the machine in practically continuous operation. Measurements are taken with the direct-reading micrometer shown in Fig. 18, Chapter V.

Magnetic Chucks. — Magnetic chucks are unexcelled for holding a large number of small parts at one time for grinding and are also adapted for a wide range of work. They are made in a variety of sizes and shapes, the form depending upon the type of grinding machine and the shape of the work. The use of magnetic chucks for internal grinding is limited somewhat; their greatest field of usefulness is on surface grinding machines of the reciprocating and rotary types. Magnetic chucks are easily and quickly operated and make it possible to obtain a greater degree of accuracy, in many cases, than could be obtained by the clamp-and-bolt method of clamping.

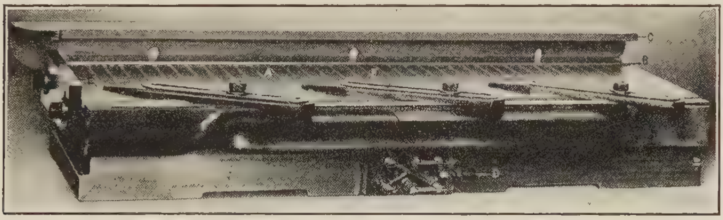


Fig. 28. Walker Rectangular Magnetic Chuck

Rectangular Magnetic Chucks. — The method of holding work to the table of a surface grinder depends, of course, more or less on the shape of the part to be ground. Ordinary clamps and bolts are sometimes used, but, where electric power is available, magnetic chucks are preferable for most work. The magnetic chuck is a special form of electromagnet which is connected by wires and a control switch with an electric power circuit. The top surface, against which the work is held, has a series of positive and negative holes which are separated by an insulating material. When in use, the chuck is clamped onto the table of the grinder, and the work is held by magnetic force when the current is turned on.

A rectangular magnetic chuck is illustrated in Fig. 28. This is the form used on surface grinders of the reciprocating type. The control switch is located at *D*, and the work is held against surface *A*, which has a number of positive and negative poles. There is a thin steel aligning strip *B* attached to the rear side of the chuck and also a vertically adjustable back-rest *C* which is used to support parts that are high in proportion to their width. In addition, there is an end-stop *E* having vertical adjustment. The work to be ground is simply laid on the chuck face, against end-stop *E* and the back-rest *C*. The slotted fingers *F*, which are provided on this particular chuck, are also used, in some cases, to stay the work edgewise and prevent it from shifting. Magnetic chucks are sometimes used on planers, as well as surface grinders, in which case, fingers *F* are of especial value.

This chuck is equipped with a duplex switch, which enables the chuck face to be demagnetized, so that work can easily be removed after the grinding operation. This demagnetizing is accomplished by simply reversing the current through the chuck coils, momentarily, until the residual magnetism is removed. In order to do this, the switch is opened and moved until the switch bars are nearly in contact with the posts at the opposite end of the switch. The handle is then gripped tightly, with the tips of the fingers, and the bars are quickly moved in and out of contact with the posts. This movement, when timed correctly, will remove the magnetism left by the previous charge. When demagnetizing, if the contact should be for too long a period, the chuck will simply become oppositely charged, and, in such a case, it can be discharged again by making quick contact with the posts on the opposite side. It should be mentioned that this switch does not demagnetize the work itself. This is necessary, however, for certain classes of work, because some materials become more or less permanently magnetized and this causes them to attract small particles, which is sometimes quite objectionable. When the work must be demagnetized, a special apparatus called a demagnetizer is used.

The way the back-rest *C* is used is illustrated by the diagrams *A* and *B*, Fig. 29, which represent end views of the chuck. The operation is that of grinding a true rectangular block *w*. While the sides are being ground, the block is held as indicated at *A*. The edges are then ground square with the sides by holding the block against the aligning strip and back-rest, as shown at *B*. Sketch *C* shows how a number of strips are held on the chuck and ground simultaneously. When parts are arranged in this way, it is sometimes advisable to place magnetic insulating strips of brass or paste-board between them, so that the magnetism will get an independent grip on each piece and hold it firmly against the face of the chuck.

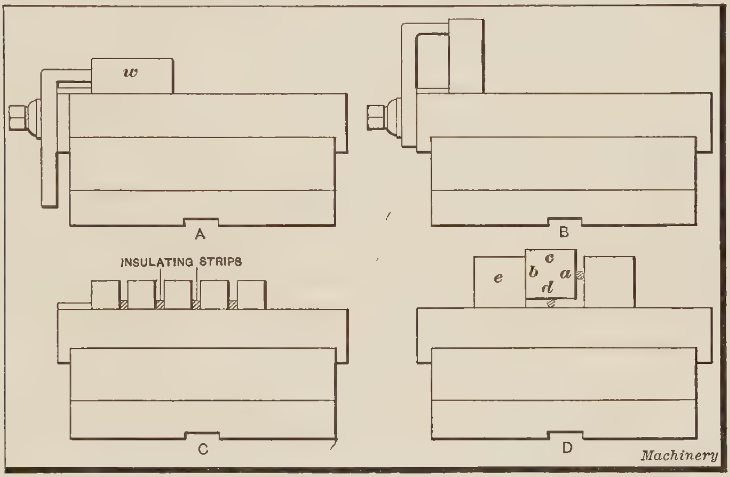


Fig. 29. End Views illustrating Different Methods of Holding Work on Magnetic Chuck

Sketch *D* shows how a piece is sometimes held for grinding the sides square to each other. Two of the sides, as at *a* and *b*, are first ground by holding the work directly against the face of the magnetic chuck. One of these finished sides, as at *b*, is then held against the vertical surface of an accurately finished square block *e*, while the upper side is ground. The lower side, instead of resting directly on the chuck face, is placed upon a piece of drill rod to reduce the contact area. In this way, the work is held more securely against block *e* than against the chuck face, because the holding power depends upon the area of the surface in contact with the magnetized part. If the side *d* were in direct contact with the chuck face, side *b* might not be held evenly against block *e*, in which case, the work would not be ground square. In this instance, the work is further secured by a block on the right side, which is separated by drill rod to reduce the contact area.

Magnetic chucks are made in many different styles and shapes. Some are so arranged that the clamping face can be set at any angle for taper grinding and others have faces that are vertical.

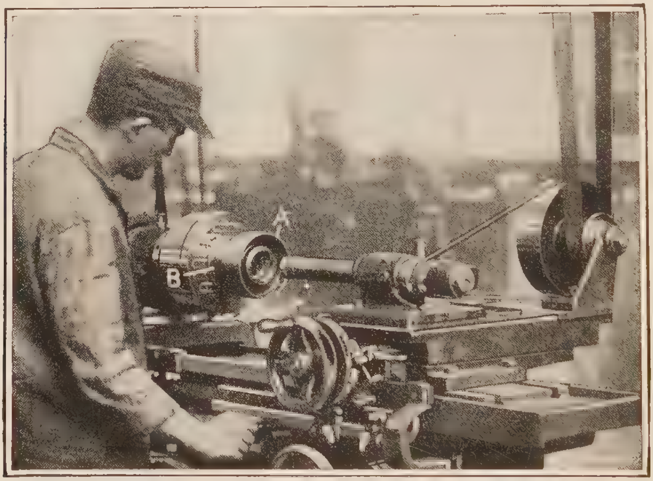


Fig. 30. Heald Rotary Magnetic Chuck on Internal Grinding Machine

There is also the rotary type and other special designs. The rotary form is used when a continuous rotary movement is required, instead of a reciprocating motion.

Magnetic Chucks for Internal Grinding. — Fig. 30 shows a Heald rotary magnetic chuck being used for holding a two-step pulley *A* when grinding the hole. The pulley is held directly to the face of the chuck by the magnetism and is prevented from shifting, and also held central, by means of retaining ring *B*. It has been found that the "grip" of the chuck is sufficient to enable quite heavy cuts to be taken with an internal grinding wheel, and the rapidity with which the work can be removed and placed on the chuck makes this method especially advantageous for certain classes of work. Magnetic chucks are applied to internal grinders for many other operations but the one illustrated is sufficient to show the general method of using them.

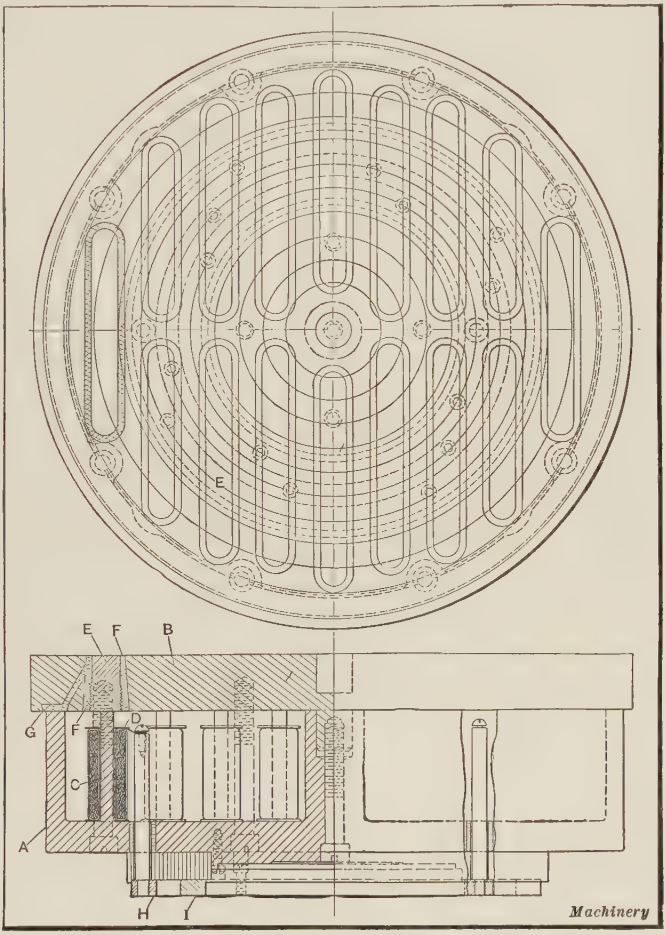


Fig. 31. Heald 12-inch Rotary Magnetic Chuck

Rotary Magnetic Chucks. — The Heald rotary magnetic chuck shown in Fig. 31 is a design intended for surface grinding machines which operate with a rotary movement. The body *A* is made from soft steel of high magnetic permeability, and the pole pieces are located close together, so that the chuck will hold smaller pieces with greater security. The chuck is so wired that the pull at any point from the center to the circumference does not vary more than 5 per cent. The faceplate *B* is held in position by brass screws from the under side, thus eliminating all screwholes on the face of the chuck. The non-magnetic material is comparatively narrow, in proportion to the width of the poles, and is held in tapered grooves. The body of the chuck has projections *C* cast integral with it, which receive the coils *D* and convey the magnetism to the pole pieces *E* in the faceplate of the chuck. The pole pieces are insulated from the remainder of the faceplate by means of a non-magnetic metal or insulation *F*. The faceplate *B* is also insulated from the main body of the chuck by a ring *G* of non-magnetic metal. The current is delivered to a set of brushes which contact with two rings *H* and *I* of conducting material. These rings are insulated from the body of the chuck by a non-magnetic ring. As to the current consumed, a 12-inch rotary chuck requires only 0.6 ampere of current, and an 8-inch rotary chuck 0.4 ampere. These chucks may be used on a direct-current circuit of either 110 or 220 volts.

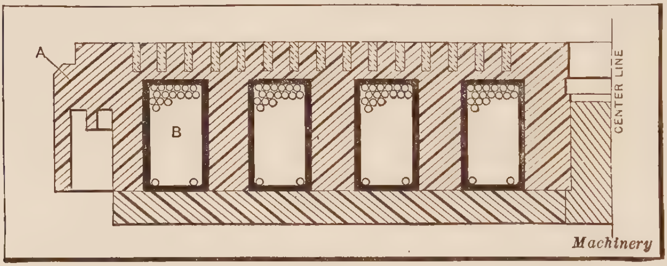


Fig. 32. Half-section of Blanchard Rotary Magnetic Chuck

A half-sectional view of a rotary magnetic chuck, that differs somewhat in construction from the one illustrated in Fig. 31, is shown in Fig. 32. This type of chuck is used on the Blanchard vertical surface grinder and is of the "fine divided pole" type. The poles are all formed on a single steel forging *A* which makes the working face of the chuck water-tight and rigid. Only four coils are used, but each coil energizes four ring poles which are so closely spaced that a piece of work of the size of a nickel would touch two poles, no matter where it is placed on the working face of the chuck. The sixteen ring poles of the chuck are also concentric. The four magnets *B* are nested one inside of the other, the shell of one magnet serving as the core of the next magnet on the outside. The chuck body has four large concentric grooves machined in one side to receive the coils, while the opposite face of the forging has fifteen small grooves machined in it to receive the brass strips which divide the face of the chuck into sixteen ring-shaped poles. These grooves in the face of the chuck are $\frac{3}{16}$ inch wide by $\frac{3}{4}$ inch deep and are filled with strip brass which is driven tightly into place. A safety flange is provided at the circumference of the chuck to prevent water from reaching the joint between the chuck body and the bottom plate. The terminals of this chuck are connected with either a direct-current circuit of 110 or 220 volts. In holding work on magnetic chucks, it becomes magnetized, and a de-magnetizer is used to remove the residual magnetism.

CHAPTER X

CRANKSHAFT AND CAMSHAFT GRINDING

THE modern method of finishing crankshaft bearings is by grinding. The bearings may either be rough-turned in a lathe, equipped for this purpose, and then be finished by grinding, or they may be ground directly from the rough drop forging. The practice in different shops varies; ordinarily, whether or not crankshafts are rough-turned prior to grinding depends upon their size and the amount of stock to be removed. When crankshafts, for automobile motors, etc., are finished directly from the rough by grinding, it is common practice to do the rough-grinding and finish-grinding in separate machines, especially when shafts are required in large quantities. In some cases, the rough-grinding machines remove $\frac{1}{4}$ inch, or more, from the pin diameter, reducing it to within 0.015 to 0.025 inch of the finished size. It is the practice, in some shops, to rough-turn only the line or main bearings of the crankshaft prior to grinding, the pins being ground from the rough.

When there is a preliminary turning operation, the total time required for machining may be considerably reduced, first, by using a turning machine that is especially adapted to this work; and second, by taking coarse roughing cuts. The rough surfaces left by the turning tool may readily be finished by the powerful machines and high-grade grinding wheels which are now available. Naturally, the grinding of the crankpins is the most important part of the operation. A common method of finishing the pins is to use a wheel that is equal in width to the width of the bearing, so that the entire pin can be finished by feeding the wheel straight in, and without a traversing movement. This is the usual method of grinding the type of crankshaft commonly used in automobile motors.

Landis Crank Grinding Machine. — A machine, designed especially for grinding crankshafts of the type used in motors for automobiles, launches, etc., is shown in Fig. 1. This machine may be used for either single-throw or multiple-throw crankshafts. The work, instead of being held upon off-set centers, is gripped at either end in special clamping holders. The crankshaft is driven from both ends, the headstock and footstock being connected by means of the driving shaft seen extending along the front of the machine. The work-carrying fixtures are provided with two independent rotary adjustments. One is an eccentric movement, which enables the machine to be used for grinding crankshafts of different throw, whereas, the other adjustment is for locating the different pins in alignment with the axes of the headstock and footstock spindles. A detail view of the work-carrying heads is shown in Fig. 2. The end of the crankshaft is rigidly clamped in bearing *A* which has a hinged cap that is held down on the shaft by a pivoted bolt on one side. By turning plate *B* to different positions, the distance between the center of the bearing and the axis of rotation is varied, in accordance with the throw of the crank to be ground. The position of a crankpin, when located for grinding, is indicated by the dotted line *D*. When grinding a multiple-throw crankshaft, the different pins are rotated around

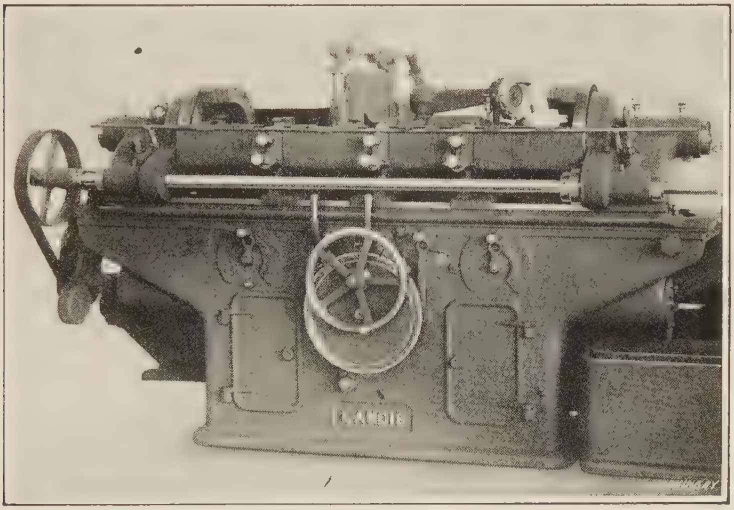


Fig. 1. Landis Crank Grinding Machine

to the central position, by turning index plate *C*. This plate has twelve notches which are 30 degrees apart, and it is accurately located by plunger *E*, which engages whatever notch may be required to align the pins. The necessary weights for counterbalancing the fixture are bolted to the faceplate at *F*.

For grinding a great many crankshafts of one throw, some Landis machines have heads of the fixed-throw type. These heads may be used for single- or double-throw crankshafts and are particularly adapted for crankshafts having a flange. The cranks are fixed in position by means of a locating pin which enters a hole in the flange. The hole is drilled centrally with the pins and is ultimately used in clamping the flywheel to the crankshaft. For grinding crankshafts of different throws, special fixtures are required in each case. This machine is intended more particularly for grinding large quantities of duplicate crankshafts.

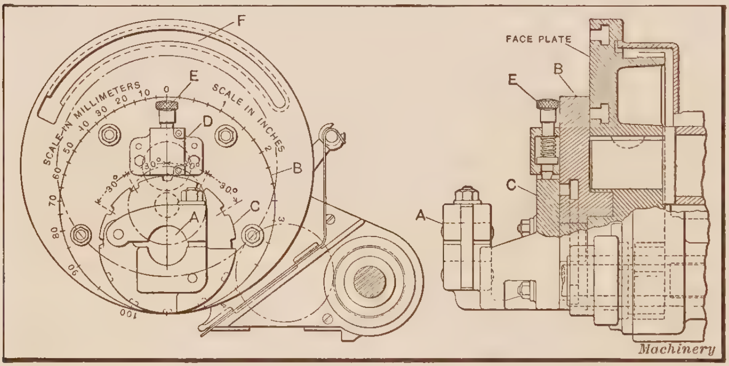


Fig. 2. Detailed View of Landis Work-carrying Head or Fixture for Holding Cranks While Grinding Pins

Locating Wheel in Alignment with Crankpins. — When crankpins are ground by using a wide wheel, which is fed straight in until the pin is ground to the required diameter, the machine is equipped with a spacing bar or attachment for quickly and accurately locating the wheel for grinding the bearings the right distance apart. The spacing attachment, which is applied to the machine shown in Fig. 1, is illustrated in Fig. 3. A bar is attached to the rear side of the bed which has notches spaced to correspond to the respective positions of the bearings. These notches are engaged by a plunger which is operated from the front of the machine by means of the lever shown.

The spacing bar of the Norton crankshaft grinder is bolted to the front of the machine table, as illustrated in Fig. 4. This bar also contains notches corresponding to the different bearings, and it is engaged by a plunger or index-pin held in a bracket attached to the bed of the machine. The illustration shows how a crankpin bearing is ground. The wheel is fed straight in and grinds the entire bearing surface. The pin being ground is supported by a special form of steadyrest. The corners of the wheel are rounded, for grinding the fillets, by a radial truing device. After one pin is ground, the spacing-bar plunger is withdrawn, and the wheel located opposite the next bearing. Obviously, these spacing attachments make it possible to grind duplicate crankshafts accurately, so far as a distance between the bearings is concerned.

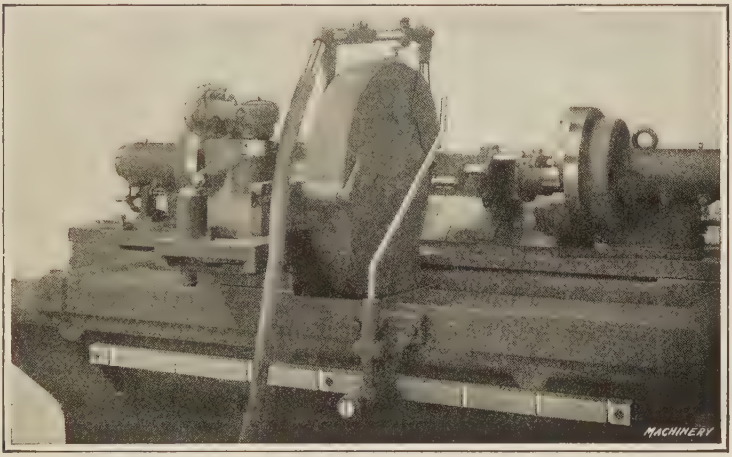


Fig. 3. Spacing Attachment of Landis Crank Grinder

Methods of Grinding Crankshafts. — In the grinding of crankshafts, the successive order of the operations naturally depends somewhat upon the type or design of the crankshaft, and, to a certain extent, upon the methods used in machining it. A general idea of the methods of procedure, however, may be obtained from the following descriptions, covering the practice in three prominent automobile plants.

One manufacturer, specializing on camshafts and crankshafts exclusively, finishes crankshafts, of the type shown at *A* in Fig. 5, as follows: On a four-throw crankshaft, the first operation consists in centering, facing the webs of the cranks, and rough-turning the line bearings to within about 0.025 inch of the final diameter. In the first grinding operation, the central main bearing is rough-ground; then the two end bearings are ground, leaving from about 0.005 to 0.007 inch for finishing. Upon the completion of the line bearings, the four crankpins are next ground from the rough forging, starting with the center one and working on both sides from the center. For grinding the crankpins, the work, of course, is held in an eccentric fixture, as previously described. On one particular size of crankshaft, a wheel 24 inches in diameter and 2 inches wide is used. For the grinding of a 0.35 per cent carbon steel, forged crankshaft, which is heat-treated, the wheel is rotated at 900 R.P.M. (5600 feet surface speed), whereas, for grinding chrome-nickel steel crankshafts, the speed of the wheel is reduced to 800 R.P.M.

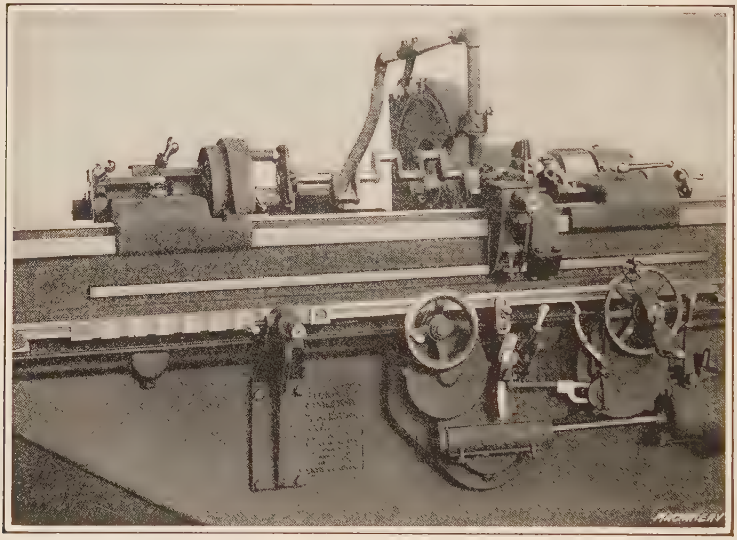


Fig. 4. Grinding a Crankshaft in a Norton Machine

(5000 feet surface speed). The work is rotated at 90 R.P.M. (35 feet surface speed) when grinding forged crankshafts either of plain carbon steel, chrome-nickel or chrome-vanadium steel. Wheels found to give good results on chrome-nickel steel forgings are, Norton alundum, grain 36 and grades *O* to *R*, for roughing, and 50 or 24 combination, grades *L* or *M*, for finishing. For grinding crankshafts made from 0.35 per cent carbon steel, heat-treated, a Norton alundum wheel, grain 36, grades *O* to *R*, is used for roughing, and, for finishing, 50 or 24 combination, grades *L* or *M*.

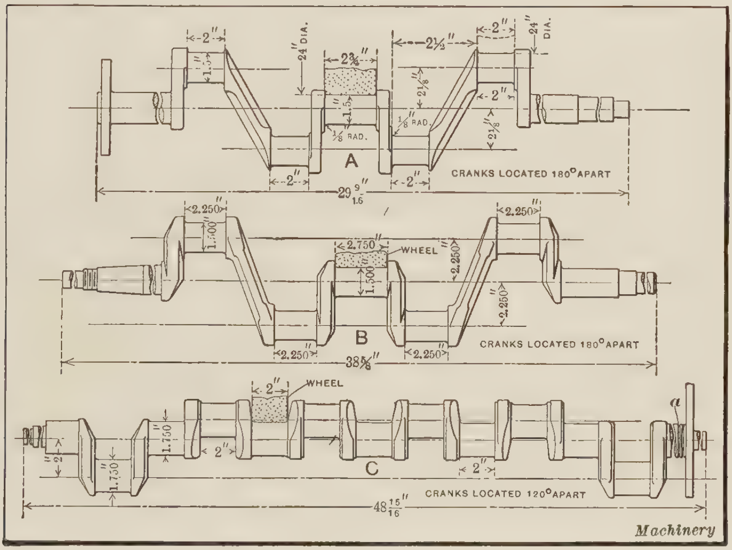


Fig. 5. Crankshafts for Automobile Motors

As a rule, sixty line bearings are turned out for each truing of the wheel for roughing, and seventy-five for finishing. The ⅛-inch radius on the wheel is formed by hand and an operator can true up a new wheel in two minutes. One steadyrest is used and it has been found that hickory blocks for the steadyrest shoe give the best results for both rough- and finish-grinding of crankshafts. This shoe, however, when rough-grinding the crankpins, is not brought in contact with the work until the wheel has removed all the scale. To grind the work round, considerable depends on the steadyrest and its manipulation. It is advisable to start at the central bearing and adjust the steadyrest there. In grinding, the steadyrest is adjusted as the wheel reduces the diameter of the work; for finish-grinding, the wheel is fed in until the diameter is within about 0.0025 inch of the final diameter. Then the wheel is not fed in further but the steadyrest is adjusted to spring the work towards the wheel. This springs the shaft out of line, to a certain extent, but has been found advantageous in producing a crankpin which is round and free from chatter marks.

Another example of crankshaft grinding is shown at *B* in Fig. 5. This particular crankshaft is made from a drop-forging of manganese steel and is heat-treated. The order of operations is to first snag the forging, then saw it to length, center, and straighten. Then the central bearing is "spotted" or ground to provide a bearing for the steadyrest on the lathe. The shoulders, short line bearings, and long bearing are next turned. The crankpins are now rough-ground, the time required being 8¼ minutes; the crankpins are then finish-ground in 8½ minutes. This operation is followed by finish-grinding the line bearings, the time being 6 minutes. The succeeding grinding operations include finishing the surfaces beyond the end line bearings. The next operation is on a lathe and consists in cutting off and threading. Holes are then drilled in the centers of the crankpins to roughly balance the crankshaft. The webs are then ground to obtain more accurate balancing. The total time, which includes a few minor machining operations, is 69 minutes. The rough-grinding operations on the crankpins are done with a Norton alundum wheel, grain 24, grade N, 24 inches in diameter, 2¼-inch face, which is rotated at a speed of 950 R.P.M., giving a surface speed of about 6000 feet per minute. For rough-grinding, the infeed of the wheel per revolution of the work is at the rate of 0.002 inch.

The two examples previously given are those relating to the grinding of four-throw crankshafts. The following description applies to the grinding of a six-throw crankshaft and covers the methods followed by a prominent automobile manufacturer.

This crankshaft, shown at *C* in Fig. 5, is made from a drop-forging of chrome-vanadium steel, heat-treated. The first operation is to "spot" both ends in a grinding machine. Then the ends are cut off to length and the shaft re-centered. The third operation consists in rough-grinding the line bearings, starting with the central one. The time required to rough-grind the seven line bearings on one crankshaft is 37 minutes. The next operation consists in rough-turning both ends to 2 inches diameter, and, at the same time, facing the inside of the flange on a geared-head lathe. The ends of the crankshaft are then ground so that they will fit the eccentric blocks used when grinding the crankpins.

The eccentric blocks are then clamped on the ends of the crankshaft, after which the crankpins are rough-ground, starting with the central pin; time, 39 minutes per shaft for the six pins. The holes for the oiling system are then drilled, after which the crankpins are finish-ground; time, 38 minutes. The eccentric blocks are now removed and the ends of the crankshaft rough-turned to size and finished for threading. The crankshaft is next straightened. After this, the outside of the flange is faced, chamfered, and the fillets turned. The seven line bearings are now finish-ground; time, 63 minutes. The oil groove *a* (see *C*, Fig. 5) is now cut, the end threaded, and two Woodruff keyways milled for the clutch. The finishing operations include balancing, drilling the flywheel flange, burring, lapping the line bearings, and inspecting. Ordinarily, there is about $\frac{1}{4}$ inch to remove from the diameter of the crankpins and line bearings. These are finished direct from the rough forging without any previous rough-turning operation. The wheel used for grinding the crankpins is 24 inches in diameter, $2\frac{1}{32}$-inch face, and is operated at a speed of 6000 feet surface speed. For rough-grinding, the work is rotated at 75 R.P.M. (34 feet surface speed) and, for finishing, about 55 R.P.M. (25 feet surface speed). The wheel found most suitable for this work was a Norton alundum, 24 combination grain, grade N for roughing, and grade M for finishing.

Wheels for Crankshaft Grinding. — The wheels used for rough-grinding crankshafts vary considerably in grain and grade from those employed for ordinary form grinding operations. Crankshaft grinding differs from other form grinding operations in that the line bearings and crankpins are not finished by one straight-in cut, but require rough- and finish-grinding operations. Generally, the same wheel is not used for both roughing and finishing, because, when rough-grinding, a harder grade of wheel is required. A harder grade is used for roughing than for finishing because of the roughness of the drop-forging, the rapid removal of the stock in grinding, and the resulting vibration of the work. Table I gives the wheels recommended for crankshaft grinding by the various manufacturers listed. Of course,

Table I. Wheels for Crankshaft Grinding

Operation	Grain	Grade	Abrasive	Grading System
0.25 to 0.50 Per cent Carbon Steel, Heat-treated				
Roughing.....	24	*O*	Boro-carbone	Abrasive Material Co.
Finishing.....	50	*M*	Boro-carbone	
Roughing.....	58–24 Comb.	*N–O*	Corundum	American Emery Wheel Works
Finishing.....	58–24 Comb.	*M–N*	Corundum	
Roughing.....	24 Comb.	*M*	Aloxite	Carborundum Co.
Finishing.....	24 Comb.	*K*	Aloxite	
Roughing.....	36	*O* to *R*	Alundum	Norton Co.
Finishing.....	50 or 24 Comb.	*L* or *M*	Alundum	
Chrome-nickel or Chrome-vanadium Steel, Heat-treated				
Roughing.....	30	*N* or *O*	Boro-carbone	Abrasive Material Co.
Finishing.....	24 Comb.	*M* or *N*	Boro-carbone	
Roughing.....	58–24 Comb.	*N–O*	Corundum	American Emery Wheel Works
Finishing.....	58–24 Comb.	*M–N*	Corundum	
Roughing.....	24 Comb.	*J*	Aloxite	Carborundum Co.
Finishing.....	36 Comb.	*K*	Aloxite	
Roughing.....	36	*O* to *R*	Alundum	Norton Co.
Finishing.....	50 or 24 Comb.	*L* or *M*	Alundum	

NOTE. The number 58 preceding, in some cases, the grain sizes, indicates a special manufacturing process for the abrasive listed.

it should be understood that the wheels used depend upon many conditions, and no invariable rules can be given for this work.

It has been found that high-carbon steel crankshafts can be ground with the wheel operating at a higher surface speed than those made from chrome-nickel or chrome-vanadium steel. In one case, where the crankshaft was made from a drop-forging of 0.35 per cent carbon steel, heat-treated, the speed found most suitable, when using a Norton alundum, grain 50, grade N wheel, was 5600 feet surface speed. On the same size of crankshaft, but which was made from a drop-forging of chrome-nickel steel, the speed found most suitable was 5000 feet surface speed. The wheel used was a Norton alundum, 24 combination grain, grade M and N. It was noticed, in making this test, that chrome-nickel steel has a tendency to glaze the wheel when running at higher speeds than 5000 feet. A variation in the carbon content of the steel does not affect the speed of the wheel very much; for diameter variations in the pins or bearings of more than about ½ inch, it is necessary to change the speeds of the wheel and work.

Cam Grinding. — The cams used on gas and gasoline motors, for operating the inlet and exhaust valves, are finished to the correct form by grinding. This grinding may be done in a regular cylindrical grinding machine, by using a suitable cam-grinding attachment. The general method of grinding cams is by so mounting the cam or camshaft that, while rotating, it will be moved toward and from the grinding wheel by a master cam, the movement causing the cam to be ground to the required form or contour. The master cam is in engagement with a roller which transmits motion to the work-holding fixture, as will be explained later. It is evident that cam grinding first involves the generation of master cams, since these must be made to suit each different form of cam that is ground.

There are two general types of attachments for grinding cams on regular cylindrical grinders. One, which is commonly known as the detachable or loose cam type, is designed for grinding cams that are not attached to the camshaft; there is also the integral cam type that is used for grinding cams that are either forged solid with the shaft or fixed to it by means of keys. The latter type of attachment is the one generally used.

Detachable Cam Grinding Attachment. — Attachments for grinding loose cams operate on the same general principle but differ, somewhat, in regard to the mechanical details. The Landis attachment is shown in Fig. 6. This attachment may be applied either to a plain or universal grinding machine by simply clamping it to the table and engaging the driving arm *A* with the regular work-driving pin which rotates with the machine face-plate. This attachment operates on the swinging principle, the work and master cam being mounted on the same spindle which is given an oscillating movement. The master cam at *C* is held in contact by a spring with a stationary shoe plate in adjustable holder *B*. The master-cam spindle is suspended from bearing *D*, and, consequently, any rotation of the cam causes an oscillating movement that serves to generate a cam at *E* of the required form. The adjustment of holder *B* is to compensate for variation in the lift of different cams.

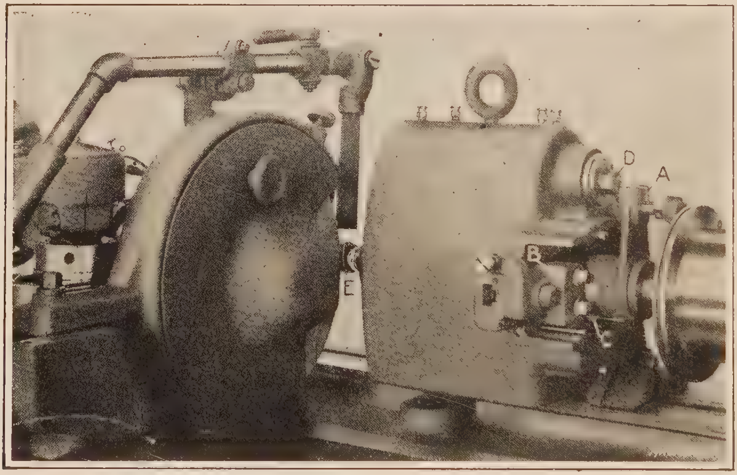


Fig. 6. Rear View of Landis Detachable Cam Grinding Attachment

In order to compensate for the reduction in diameter of the grinding wheel as a result of wear, the shoe plates are provided in sets, there being one for each inch of grinding wheel diameter reduction. The contact surface of each plate is curved, the curve, in each case, representing that of the grinding wheel at different diameters; thus, each plate has a different radius and the number of plates in a set is determined by the diameter of the grinding wheel at its full size and the smallest diameter to which it can be reduced on the particular grinding machine on which the attachment is used. The wear of the wheel does not affect the length of the cam being ground, nor the diameter of its cylindrical portion, but it does affect the contour of the cam at the sides; hence, the use of different guide plates to compensate for wheel wear.

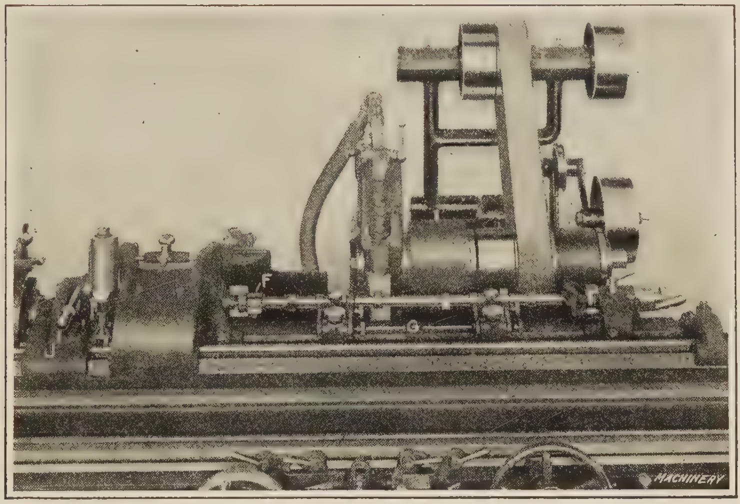


Fig. 7. Norton Integral Cam Grinding Attachment

Integral Cam Grinding Attachment. — A Norton attachment, for grinding cams that are forged solid with the shaft, is shown in Fig. 7. The camshaft is mounted between the center of the master-cam spindle and the center of a footstock which supports the outer end. Both the master-cam spindle and the footstock are mounted on a member which is free to oscillate. This oscillating or swinging movement is caused by the engagement of master cams *B* (see rear view, Fig. 8) with the roller *C* which revolves on a fixed shaft. The master cam and camshaft are rotated from the headstock of the machine through a driving arm and the gearing shown. There is one master cam for each cam to be ground. These are located in correct positions, relative to one another, so that the different cams are ground by simply sliding roller *C* from one master cam to the other. This roller is located opposite the different master cams by an index-pin which engages holes in plate *A*. The master cams are held against roller *C* by an encased spring *E*. The grinding wheel is fed against the work in the usual manner. Handle *J* on the attachment is used to move the work away from the wheel for inspecting it while grinding or when moving roller *C* from one position to another.

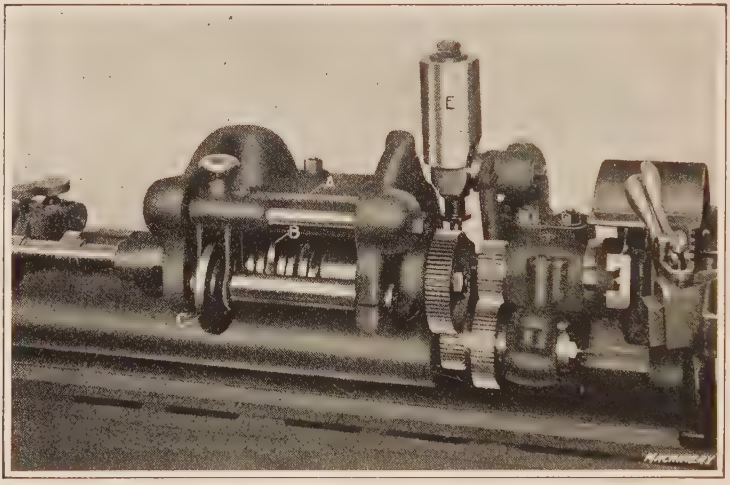


Fig. 8. Rear View of Norton Attachment showing Master Cams

The camshaft is supported while being ground by steadyrests *G*, the number required depending upon the length and rigidity of the shaft. The two general types of steadyrests used are the open and closed designs shown in Fig. 9. The open type *A* has the advantage of being more easily applied to the work and removed, and has proved satisfactory, but, when very accurate grinding is necessary, the closed type *B* is recommended. As will be seen, these steadyrests simply form a bearing, and they are generally applied to the same bearing surfaces that are used when the camshaft is assembled in the engine. Ordinarily, hardened steel work-shoes are used, although it is sometimes necessary to use bronze shoes. The shoe, for the open type of steadyrest, should have one bearing surface opposite the grinding wheel and the other on the opposite side of the vertical center-line, to steady the shaft in the direction of the wheel rotation. The camshaft is rotated by a special form of dog *F* (see Fig. 7) which is located in the proper position by means of a keyway.

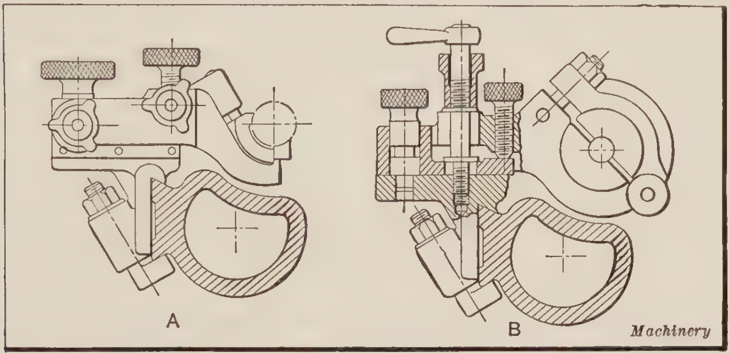


Fig. 9. Open and Closed Types of Steadyrests for Cam Grinding

The Landis integral attachment, illustrated in Fig. 10, operates on the swinging principle; the fixture or table carrying the work and master cams is supported by bearings at each end, which permit an oscillating movement as the master cams revolve in contact with a stationary roller attached to the machine table. This roller is in contact with a master cam, corresponding in location to the cam being ground, and it is shifted along the table of the machine as the grinding wheel is moved from one

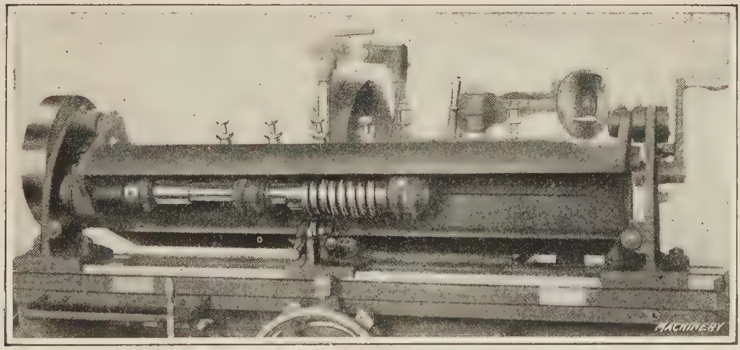


Fig. 10. Landis Integral Cam Grinding Attachment

cam to another on the work. When shifting the roller, the table of the fixture is swung away from the wheel, by operating the upright lever or handle seen at the extreme right. The camshaft is supported by adjustable steadyrests in addition to centers; these steadyrests have detachable jaws which can readily be changed for different sizes of shafts. The work driver may be adjusted around the spindle for locating the cams in the proper relation to the keyway in the shaft.

Table II. Wheels for Cam Grinding

Operation	Grain	Grade	Abrasive	Grading System
0.25 to 0.50 Per cent Carbon Steel, Heat-treated				
Roughing.....	24	*P*	Boro-carbone	Abrasive Material Co.
Finishing.....	46	*J*	Boro-carbone	
Roughing.....	58–16	*O* to *Q*	Corundum	American Emery Wheel Works
Finishing.....	58–46	*J* or *K*	Corundum	
Roughing.....	24	*I*	Aloxite	Carborundum Co.
Finishing.....	40	*N*	Aloxite	
Roughing.....	24 Comb.	*N* or *O*	Alundum	Norton Co.
Finishing.....	38–24 to 46	*I*, *J*, *K*	Alundum	
Chrome-nickel or Chrome-vanadium Steel, Heat-treated				
Roughing....	24	*P*	Boro-carbone	Abrasive Material Co.
Finishing....	46	*J* or *K*	Boro-carbone	
Roughing.....	58–16	*O* or *P*	Corundum	American Emery Wheel Co.
Finishing....	58–46	*J*	Corundum	
Roughing.....	16 Comb.	*I*	Aloxite	Carborundum Co.
Finishing.....	36 Comb.	*K*	Aloxite	
Roughing.....	24 Comb.	*N* or *O*	Alundum	Norton Co.
Finishing.....	38–24 to 46	*I*, *J*, *K*	Alundum	

NOTE. The numbers 38 and 58 preceding, in some cases, the grain sizes, indicate a special manufacturing process for the abrasive listed.

Wheels for Cam Grinding. — The grain and grade of wheels for cam grinding vary in accordance with the conditions in each case, the same as with other grinding operations. The material to be ground, the accuracy and finish required, and whether the cut is roughing or finishing should be considered. The general practice is to use a wheel that is medium hard or a little softer for roughing, whereas, for finishing, the wheels are usually from one to three grades softer than medium. The wheels listed in Table II have been used for cam grinding with satisfactory results.

Speeds for Grinding Wheel and Camshaft. — For cam grinding, a wheel speed of from 6000 to 6500 feet per minute is recommended. The work speed depends, as in ordinary cylindrical grinding, largely upon the grade of the wheel. When grinding cams, which are integral with the shaft, and using the alundum wheels listed in the foregoing table, the speed for roughing should vary from about 40 to 60 revolutions per minute; whereas, for finishing, the speed should vary from 15 to 20 revolutions per minute. It is desirable to determine the speeds, in each case, by trial. It is common practice to use higher speeds than those mentioned, especially when grinding with comparatively hard wheels, but, for accurate work, the softer wheels and slower speeds are recommended.

Testing Accuracy of Cam Grinding. — A fixture for testing the accuracy of camshafts and model cams is shown in Fig. 11. This fixture indicates whether or not the cams are ground so as to open and close the valves at the correct time. The cam to be tested is placed in engagement with a plunger *A* which is connected with the dial gage shown. This plunger should correspond with the type of lifter to be used on the motor; that is, whether it is to be the roll type, the mushroom type, or a special design. If the roll type, the diameter of the roll on the testing fixture should correspond with that on the motor. When making a test, the camshaft is turned so that roll *B* is in contact with the concentric part of the cam. The dial gage is then adjusted so that the hand stands away from the zero position an amount equal to the clearance required. (The clearance is the distance that the lifter is moved by the cam before it operates the valve; the clearance ordinarily allowed varies from 0.006 to 0.010 inch.) After setting the dial gage to represent the clearance, the cam is rotated so as to turn the dial hand to the zero position. This represents the opening point of the valve.

With the cam set at the opening point, the graduated wheel *E* is moved until pointer *D* is opposite the zero mark on the wheel. The cam and pointer are then rotated in such a direction that roller *B* moves over the concentric part of the cam. When the roller reaches the cam surface and the indicator hand is again at zero, this represents the closing point. By noting the number of degrees that wheel *E* has moved from zero position, and deducting this number from 360 degrees, the angle through which the cam rotates, while the valve is held open, will be accurately obtained.

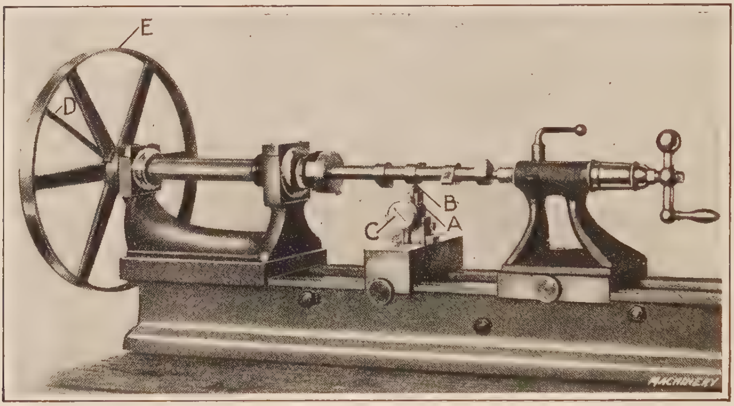


Fig. 11. Fixture for Testing Accuracy of Ground Cams

The lift of the cam may be determined first, by measuring, with a micrometer, the over-all length or the distance from the highest point to the concentric surface on the opposite side, and then deducting the diameter of the concentric part.

Grinding Master Cams. — The master cams, which are used on a cam grinding attachment, are produced by reversing the operation of grinding a cam. The method of generating one of these master cams for the Norton attachment illustrated in Fig. 7 is indicated by Fig. 12. A disk *A*, of the same diameter as the regular grinding wheel, is mounted on the spindle of the machine and bears against the model cam which it is desired to reproduce. The master cam to be ground, instead of being against a roller, is in contact with a small grinding wheel *B*, which, for finishing, is the same diameter as the roller that normally engages the master cams when the attachment is being used. This wheel *B* is driven by a separate belt, as the illustration shows. The hardened master cams are previously roughed out to approximately the required form and are properly located with reference to one another.

As the model cam revolves in contact with disk wheel *A*, a rocking or oscillating movement is imparted to the attachment,

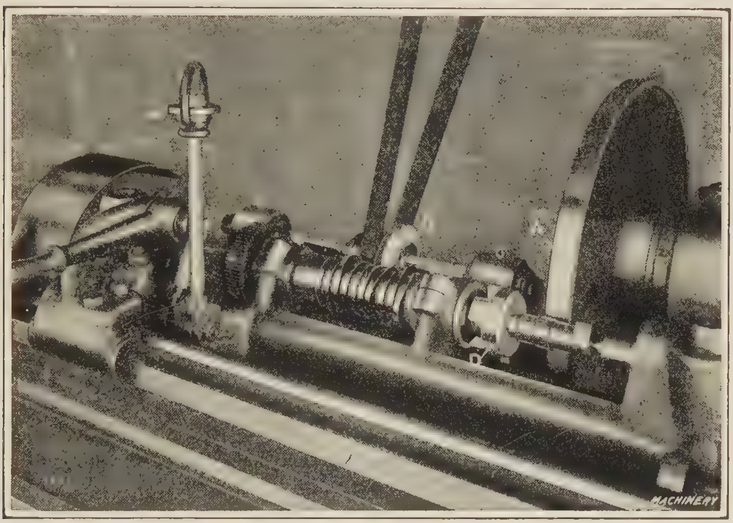


Fig. 12. Method of Grinding Master Cams for Attachment shown in Fig. 7

and one of the master cams is ground by wheel *B*. The dog *D*, for driving the model cam, must bear exactly the same relation to the model cam as the regular driving dog bears to the corresponding cam on the camshaft in the cam grinding operation. This dog, for a four-cylinder motor, has four slots spaced 90 degrees apart. One of these slots engages a driver, so that the master-cam spindle may be indexed with reference to the model cam for grinding the different blanks.

A feeding-in movement for grinding is obtained by moving the regular wheel slide away from the operator. When starting to grind, the disk *A* must be moved towards the operator, so as to force the attachment, which carries the master-cam blanks, to swing away from the grinding wheel far enough to allow starting the grinding operation. As the grinding proceeds, the wheelslide is gradually moved back, until the desired shape is obtained. The position is governed by the smallest master cam. When this has been trued, the reading of the index wheel is noted, and this determines the stopping point for all of the blanks. The number of master blanks always corresponds to the number of cams on the camshaft.

A grinding wheel which has proved satisfactory for grinding master cams is a Norton alundum, grain 46, grade 3, elastic, with a $\frac{3}{8}$-inch face. When rough-grinding, the wheel may vary from $3\frac{1}{2}$ to $4\frac{1}{32}$ inches in diameter; for finishing, however, the wheel diameter should be within the limit of from 3.998 inches to 4.002 inches. The face should be carefully trued and the speed should be approximately 3800 revolutions per minute.

CHAPTER XI

DISK GRINDING

The disk grinding process derives its name from the fact that the grinding is done by a disk or "circle" of abrasive cloth or paper, which is cemented or glued to a steel disk-shaped wheel that revolves at a suitable speed, although, regular ring wheels are now used for many disk grinding operations. This method of grinding is very efficient for many classes of work and is employed principally for truing plane surfaces. Most disk grinding is done without rigidly clamping the work; the casting or forging is pressed against the side of the disk wheel while held in the hands or in a suitable fixture. Rigid clamping should be avoided, if possible, not only because of the time required but also because it is desirable to present the work to the wheel in such a way that it will have a free "floating" movement. In some cases, clamping is necessary, but when the work is held in a fixed position, more material, as a rule, must be removed, in order to produce a true surface.

Types of Disk Grinders. — The principal types of disk grinders are the single-spindle type, which is the one most commonly used; the double-spindle machine, which is a more recent development; the vertical-spindle design; and the patternmakers' disk grinder. There is also a combination single- and double-spindle machine, and automatic and semi-automatic designs have been used to a limited extent. The single-spindle disk grinder (see Fig. 1) has a disk wheel on each end of the spindle, so that two men may use the machine simultaneously. The work-tables may be set at right angles to the disk wheel, or, at an angle greater or less than 90 degrees, when grinding angular work. These tables are so mounted that they can be given an oscillating movement for traversing the work across the abrasive disk or grinding wheel.

The vertical-spindle type has a large disk wheel (see Fig. 2) which revolves in a horizontal plane. In operating this machine, the parts to be ground are simply laid upon the revolving disk and are prevented from rotating with the disk by a cross bar. If the weight of the work is equal to three or four pounds pressure to the square inch of area to be finished, no additional pressure is required, but in case it is much less than that, the output can be greatly increased by putting an additional weight on top of the work. The illustration shows the machine grinding gas engine base castings, four of these castings being placed on the disk and ground simultaneously. This particular operation was simply to produce a flat even bearing surface without removing any unnecessary stock. The time for doing this work is about one minute per casting. This machine is also very efficient for many kinds of free-hand grinding, no effort being required to support the work; tests made with different classes of work are said to have shown very efficient results.

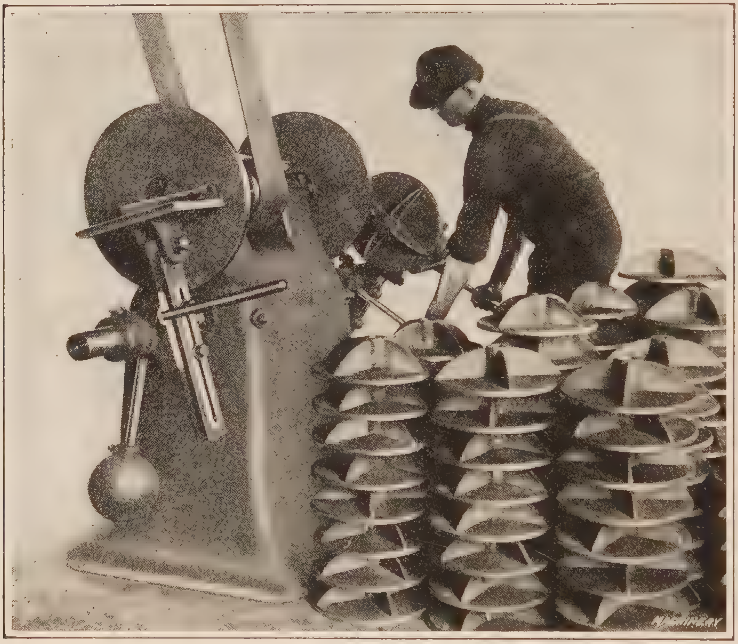


Fig. 1. Besly Single-spindle Disk Grinder being used for Grinding Ends of Bosses on Cast-iron Plates

The double-spindle machine has two disk wheels, so located as to grind both sides of the work at the same time, as indicated in Fig. 3. The castings being ground, in this particular case, are held in a small wooden fixture, and, as the sides are only about $\frac{1}{16}$ inch thick, each casting is filled with water before inserting it between the disks, to prevent excessive heating and distortion. The distance between the wheel-faces of a double-spindle machine may be varied, and, when grinding, the wheels may be fed against the work either by a hand lever or a foot lever.

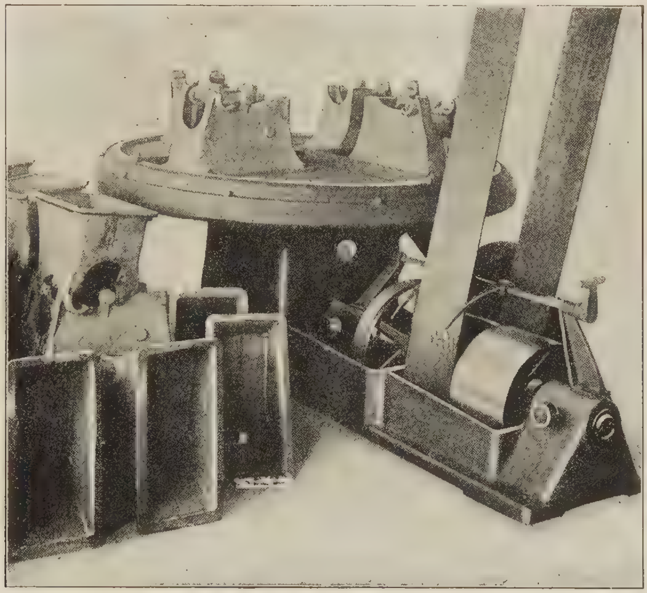


Fig. 2. Four Gas Engine Base Castings being Ground Simultaneously on Gardner Vertical-spindle Disk Grinder

Machines of this type are so arranged that either one wheel or both may be fed inward; when feeding only one wheel, the other wheelhead is held in a fixed position. For rough-grinding work, preparatory to polishing, the double-disk machine is far more economical than an ordinary floor grinding machine, on which the work is applied to the periphery of the wheel, especially when grinding hexagon cast-brass or cast-iron nuts, the heads of bolts, wrenches, etc.

Methods of Feeding Work Against Disk Wheel. — There are three common methods of feeding the work against the disk wheel; namely, by hand, by means of a lever which imparts motion to the work table, and by gravity feed. When the part to be ground is simply pressed against the side of the disk wheel by the operator, this is usually known as "free-hand grinding" and is a method often followed when grinding castings or other parts which are comparatively light and have small surfaces that require truing. This method is employed for smoothing, cleaning, burring, or light snagging operations on castings, and is very rapid for this class of work. A table is sometimes used when the work is fed by hand, especially if the ground sur-

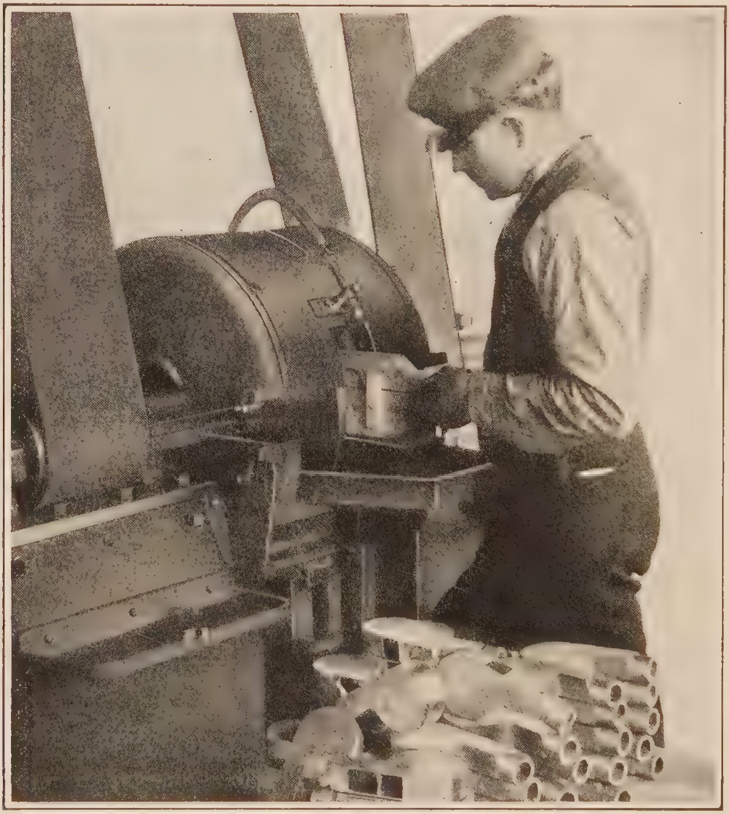


Fig. 3. Double-spindle Type of Disk Grinder

face must be true with reference to some previously finished surface. For instance, when surfacing the narrow edges of small brass parts or castings, requiring a comparatively light pressure, the work is simply placed upon the table and pressed against the wheel by hand. Obviously, this is also a rapid method.

For grinding operations, excepting on small surfaces and light work, some kind of a mechanical device for pressing the work against the disk wheel is essential, in order to secure efficient results. A common arrangement is to equip the grinder with a sliding work-table which is actuated by a hand lever. The work may be held in position by an ordinary angle-plate or some special form of fixture. In most cases, this fixture is so designed that the part to be ground is simply supported on the side opposite the wheel, but is not clamped in position.

The gravity feed, previously referred to, is the natural method of feeding when using a disk grinder of the vertical-spindle type, inasmuch as the grinding wheel, in this case, revolves in a horizontal plane. If the part being ground is too light to give sufficient pressure, it is the usual practice to lay a weight upon it. In any case, it is seldom practicable to get a feeding pressure that will enable the grinding to be done as rapidly as on a horizontal-spindle disk grinder equipped with a lever feed; therefore, grinding by the gravity feed requires more time. The vertical-spindle disk grinder, however, is especially adapted for grinding parts that are too large or heavy to be handled conveniently on a lever-feed grinder; this type of machine is also efficient for grinding a large number of pieces simultaneously.

Effect of Heat Generated by Disk Grinding. — All disk grinding is done dry or without cooling water, because the latter would injure the abrasive disks; consequently, considerable heat is generated and this may distort the work to such an extent that unsatisfactory results are obtained, unless the proper method is followed. For instance, when grinding the side of a casting, the part next to the wheel expands more than the outer side, thus warping the work. Obviously, if the grinding is continued with the part thus distorted, the ground surface will not be true when the casting has cooled and contracted. For this reason, it is quite common to find parts that are ground slightly concave, and, in some cases, a surface of this form may be a slight advantage. When a true surface is required, the work, after the rough surface has been removed, is allowed to cool, or is left until the temperature is equalized, and is then ground lightly; the wheel will quickly reduce the uneven or high spots. In some instances, it may be necessary to repeat this operation a few times before a satisfactory surface is obtained.

Parts having parallel sides, both of which are to be finished, can be ground to advantage between the two disks of a double-head machine, because both surfaces are ground simultaneously and heated equally so that no springing or warping occurs. When using a single wheel, it is better to handle the work several times, rather than to overheat it by long-continued grinding. Aside from the trouble due to warping, hot metal is not ground as easily as cold metal, and it also has an injurious effect upon the bond of the abrasive disk. Grinding parts until they become red hot is very bad practice. The amount of heat generated in grinding can be reduced by the use of sharp disks of fairly coarse grain. The feeding pressure should also be sufficient to make these coarse grains cut so that the stock will be roughed off quickly. When the disk becomes dull and glazed, its cutting qualities can sometimes be improved by passing a grinding wheel dresser lightly over the surface. A stiff wire brush, such as is used for cleaning castings, is also used as a disk dresser when grinding parts of brass, aluminum, cast iron, etc. Roughing and finishing operations are necessary on many classes of disk grinder work, especially if extreme accuracy is required.

Abrasives for Disk Grinding. — Many of the abrasive materials used in grinding wheels are also employed for disk grinding. The abrasive is attached to cloth or paper disks, which are glued or cemented to the sides or faces of steel disk wheels and vary in diameter from 10 to 30 inches for ordinary disk-grinding operations on machines of the horizontal-spindle type. The coarseness of the grains is designated by numbers. For example, a No. 36 disk is one having abrasive grains that will just pass through a sieve having 36 meshes to the linear inch. The principal grains used in modern disk grinding practice are 12, 16, 24, 36, 46, 60, 90, and 120. The numbers generally used are 12, 16, 24, and 36. Most disks or "circles" have cloth backs. Paper-back disks can be employed to advantage on many light "smoothing" jobs but should not be used for a coarser grain than No. 24.

The durability or life of an abrasive disk depends not only upon the quality of the disk but upon the kind of material ground with it, the general condition of the disk grinder, and the skill of the operator. It is very important, when grinding, to press the work against the wheel with a uniform but firm pressure. A sudden jamming of the work against the disk will greatly affect its life. On the other hand, too light a pressure tends to dull the disk and increases the time required for grinding. When the work is being ground, it should be rocked across the face of the disk for ordinary grinding operations, as this rocking motion distributes the wear, thus increasing the durability of the disk and enabling truer work to be ground. In grinding with stationary work-rests, the part being ground should be moved back and forth on the rest while in contact with the disk.

Selection of Abrasives for Disk Grinding. — The following general information, regarding the selection of abrasives for disk grinding different metals, is given by the Gardner Machine Co.: Use nothing coarser than grain No. 16 for grinding a surface of less than 3 square inches area. Use nothing coarser than No. 16 on soft steel or brass, even if the area is large. Use nothing coarser than No. 24 for hardened steel, whatever the size of piece, and seldom use coarser than No. 24 on brass, unless there is a large amount of stock to be removed from rough castings. For brass, grain No. 36 is a good number, as it cuts fast and leaves a fairly fine finish which can easily be polished by buffing or with a very fine disk. No. 46 is used considerably for grinding small surfaces on brass, and for finish-grinding soft steel and cast iron, after rough-grinding with a No. 16 or No. 12 disk. For grinding cast iron, when the area of the surface is more than 3 or 4 square inches, use from No. 16 to 12. It is a mistake to use fine numbers on cast-iron scale. If a fine surface is required, it is much better and more economical to first rough-grind close to size and then finish with finer numbers.

The following suggestions are given by Charles H. Besly & Co. as a guide in selecting grain numbers for various disk grinding operations: The best "circles," for general grinding, are grain Nos. 16 and 24. For rough grinding cast iron, malleable iron, bronze, etc., use nothing finer than grain 16 on areas larger than 2 square inches. On smaller areas, use nothing coarser than No. 24. For rough-grinding cast brass, use nothing coarser than No. 24, except on extremely large scaly surfaces, in which case, a grain as coarse as No. 16 can sometimes be used to advantage. Most rough-grinding on brass castings is done with circles or disks of No. 36 grain, as they are coarse enough to remove stock rapidly and fine enough to leave a finish that is satisfactory for many classes of work. When a fine finish is required on brass, circles of No. 60 grain are used extensively, No. 36 being used first for roughing and No. 60 for finishing. No. 46 circles are often satisfactory for roughing and finishing small brass parts in one operation. On extremely hard material, it is a mistake to use very coarse grains. For hardened steel, chilled iron, and very hard unannealed tool steel, use nothing coarser than No. 24. Circles of No. 36 grain are employed for grinding hard forging dies and casehardened valve gear parts in locomotive shops.

Allowances for Disk Grinding. — The amount of stock to be removed, the area of the ground surface, and its distribution are important factors in disk grinding. The removal of from 0.005 to 0.050 inch of stock will usually "clean up" a surface. The following figures, taken from actual practice, represent allowances used in connection with Besly disk grinders: Drop-forged wrenches, from 0.008 to 0.015 inch; brass hexagon nuts up to 2 inches in diameter, 0.015 inch; larger sizes, up to 0.030 inch; steel punchings, from 0.005 to 0.015 inch; cast-iron machine parts, from $\frac{1}{32}$ to $\frac{1}{16}$ inch; cast-brass machine parts, from $\frac{1}{64}$ to $\frac{3}{32}$ inch. The amount of stock that can economically be removed by disk grinding depends largely upon the nature of the material being ground. Cast metal is more easily ground than rolled or wrought material, and small thin castings are usually harder to grind than larger and thicker castings, owing to the greater density of the metal. When castings have a hard scale, it is often desirable to partially remove it before disk grinding. The hard scale is "broken up" either by grinding on vitrified wheels or by tumbling, sand blasting, or pickling. The latter method is the best for forgings or hot rolled material that has considerable scale.

Speeds for Disk Grinding. — Speeds recommended for disk grinding must necessarily be a compromise, because the speed, at any given point on the side of a disk wheel, depends upon the radius; hence, if the speed near the circumference is correct for grinding a certain class of work, the central part of the disk will be running too slowly. Therefore, it is important to consider the average speed. The speeds given in the table, "Speeds of Wheels for Disk Grinders," are recommended by Charles H. Besly & Co. They are given in revolutions per minute for disk wheels of different diameters and are based on the following averages: For grinding steel, cast iron, bronze, etc., an average abrasive speed of 5000 feet per minute; for grinding brass or for burring and finishing, 6500 feet per minute; for grinding aluminum alloy and very soft material, like artificial rubber, 7500 feet per minute; and for grinding wood, 4000 feet per minute. When grinding hard metals, an excessive speed will dull and glaze the disks; too slow a speed for soft metals tends

Speeds of Wheels for Disk Grinders

Diameter of Disk Wheel, Inches	Speed in Revolutions per Minute			
	For Cast Iron and Steel	For Brass and for Burring and Finishing	For Aluminum Alloys	For Wood Grinding
12	2000	2600	3000	1600
18	1400	1800	2100	1100
20	1250	1600	1900	1000
23	1100	1300	1650	850
26	1000	1250	1500	800
30	900	1150	1350	750

to fill and clog the disks. Too high a speed for wood tends to burn the work. The Gardner Machine Co. recommends the following speeds, which represent velocities at three-fourths the radius of the disk wheel: For grinding cast iron or steel, from 4000 to 4500 feet per minute; for grinding brass, from 5000 to 5500 feet per minute. A speed of 5000 feet per minute is given as the maximum for cast iron and steel. If the grinder is to be used for both steel and brass and is without means for changing the speed, slower speeds, ranging from 4000 to 4500 feet per minute, are recommended. The speeds, given in the foregoing, represent average practice, and variations may be necessary for certain classes of work.

Feeding Pressure for Disk Grinding. — The feeding pressure that will give the most accurate results for disk grinding depends upon the nature of the work, the area of the surface being ground, and the grade and condition of the disk. According to the Gardner Machine Co., a pressure of less than 10 pounds per square inch of ground surface is ordinarily not sufficient, if very much stock is to be removed. A feeding pressure of from 20 to 30 pounds per square inch will be found a fair average, and 40 pounds is practically the limit of pressure. While the life of an abrasive disk depends largely upon the kind of material being ground, the length of time a disk will cut effectively can be greatly increased by proper feeding. Any sudden jamming of the work against the disk, either by hand or with a feed lever, will soon destroy its cutting qualities, whereas, too light a pressure tends to dull the disk before a sufficient number of parts have been ground. Charles H. Besly & Co. give the following information regarding feeding pressures: On most work, the feeding pressure for rapid rough-grinding varies as follows: Cast gray iron, from 60 to 80 pounds per square inch; soft malleable iron, from 20 to 40 pounds per square inch; yellow brass castings, from 20 to 30 pounds per square inch; hot rolled mild steel, pickled, from 25 to 50 pounds per square inch. In exceptional cases, a feeding pressure of 100 pounds per square inch of ground surface area has been used without destructive effect on the circle.

Attaching Abrasive Disks. — Before a new abrasive disk is applied to a disk wheel, the latter should be clean and dry. If the disk wheel is greasy, it should be cleaned, before applying the cement, by washing in a rather strong and hot solution of potash or concentrated lye, rinsing with hot water. Do not apply the glue or cement until the wheel is dry. The disk wheel should remain in the press from 15 minutes to an hour, depending upon whether glue or cement is used. It may be left in the press for a much longer period, if convenient. The wheel should be allowed to dry thoroughly after being taken from the press and before using. Artificial heat should not be used for drying. Ordinary patternmakers' glue is often used for attaching disks, but the special disk wheel cements, sold by disk grinder manufacturers, are generally considered more satisfactory. When hot glue is used, the steel disk should first be warmed, but cement may be applied to a cold wheel. To remove worn-out disks or circles, immerse the wheel in water. Cold water can be used, but hot water will loosen the disks much quicker. The disks should be stored in a cool, dry place. They should be kept free from oil, grease, or water, and not be subjected to dry artificial heat, especially heat from direct steam radiation, as this will injure the bond, causing the cutting particles to shell off when in service.

Reduction of Area to be Ground. — The efficiency of the disk grinding process can often be greatly increased by recessing the patterns for castings, so that surfaces of unnecessary width are avoided. This reduction of the surface often makes it feasible to finish parts by disk grinding that otherwise would have to be machined by other and slower methods, and even on small castings, it is economical, in many cases, to change the patterns, in order to reduce the width or area of joints, etc., because the castings can be ground much more rapidly and there is less wear on the abrasive disks. What has been said regarding patterns also applies in principle to forged parts; that is, the more stock removed, the less economy, this being especially true in the case of harder metals, such as iron and steel.

Grinding Soft Metals. — When grinding soft metals, such as copper, babbitt, and aluminum, the tendency is to clog the abrasive disk. This is especially true of copper and babbitt metal. Aluminum castings vary considerably but are generally easy grinding, although, in some cases, they also tend to clog the disk. To prevent this clogging, wax is sometimes applied to a new disk by rubbing it over the wheel while the latter is stationary, thus filling the spaces between the abrasive grains before beginning to grind. After grinding two or three minutes, or until the disk seems to be cutting less freely, a rather fine wire brush is passed lightly but firmly across the disk wheel while running. This removes the soft metal chips that have adhered to the waxed disk and also the loose wax. Another coating of wax is then applied, while the disk is running, and the grinding operation continued. This operation is repeated until the disk is worn out or the grinding completed. The removal of the wax and chips, by means of the brush, should not be delayed too long, because, in that case, small masses of soft metal will become imbedded in the disk and spoil its cutting qualities; it is also more difficult to clean a disk after it has become partly clogged by soft metal than it is to keep it clean by the method referred to. A waxed disk does not cut soft metal quite as fast as a dry one, but soft metal will destroy a dry disk in a comparatively short time.

There are a few materials which are not readily ground by disk grinding. Among these may be mentioned rolled copper, lead, glass, and porcelain. Rolled copper is so tough that it tends to dislodge the abrasive from the cloth backing. While rolled copper has been successfully finish-ground, difficulty will be experienced if an attempt is made to remove much material. Cast copper is ground more easily than rolled copper. Glass heats and cracks; the disk grinder, however, has been successfully used for finishing the ends of glass tubes, very little stock being removed. Lead is so soft that it clogs and fills the interstices between the abrasive grains, whereas, porcelain heats and cracks.

Rotary Disk Grinding. — The area that is in contact with the grinding disk is reduced, on some classes of work, by what is known as the rotary process. Fig. 4 illustrates the principle. The part to be ground is held by means of a magnetic chuck, a faceplate, or a special fixture that is mounted in bearings and is free to rotate. The work-table of the disk grinder is located so that the abrasive disk only makes contact with one side of the surface to be ground, as the illustration shows. The action of the grinding wheel rotates the work, so that the entire surface is ground as the result of the rotary motion. The rotary method is employed when the surfaces to be ground are large and unbroken and considerable stock must be removed; when the work is thin and easily heated in grinding, or fragile and easily sprung; and also, when an accurate plane surface is required. It is claimed that much larger surfaces can be ground successfully by the rotating method, because the abrasive grains zigzag in and out across the work and are quickly relieved of the grindings; moreover, the continual crossing of the cuts, due to the rotary motion of the work, results in faster grinding and tends to prevent glazing of the disk. Thinner work can also be ground, because less heat is generated.

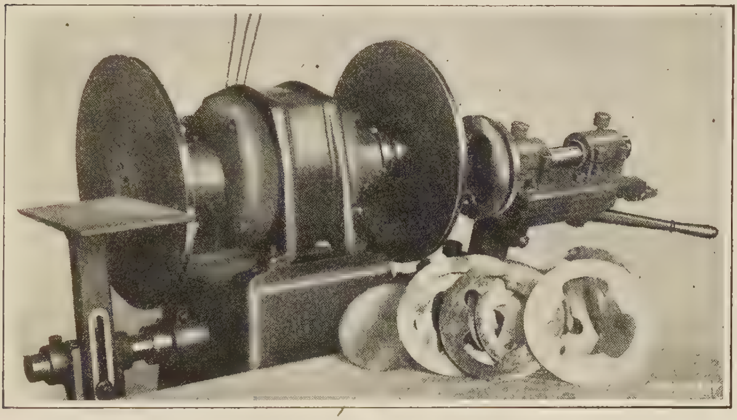


Fig. 4. Rotary Method of Disk Grinding

The form of the rotary work-holder naturally depends upon the shape of the part to be ground. For pieces having rough uneven surfaces, it is often desirable to seat the work on three pins or studs, projecting from the fixture or plate. A rotary work-holder should be in running balance when the work is in place, in order to reduce vibration. This balancing may be effected by means of counterweights. In some cases, however, little or no balancing is required, provided the work is properly located with reference to the axis of rotation. In some cases, especially if the work is thin and fragile, it may be difficult or impossible to chuck it carefully enough to obtain a perfectly flat surface after the part is released from the fixture. In such cases, after the work has cooled, it can be given a light finishing cut without the use of a fixture and by simply pressing it against the side of the wheel or by "free-hand grinding."

A rotary grinding attachment, which is applied to some disk grinders, is so arranged that the work-spindle is rotated by a handwheel rather than by the action of the grinding wheel, connection being made between the handwheel and work-spindles by worm gearing. Instead of the handwheel, a driving pulley is substituted, in some cases, and a motor drive is employed.

Ring Wheel Grinders. — Grinding wheels of the ring type are applied to disk grinders for many operations, instead of using the regular steel disks faced with abrasive cloth. These ring wheels, which are held in special chucks, are especially adapted for operations requiring the grinding of a comparatively large amount of stock, or when water cooling is necessary. For instance, when grinding castings having a hard scale, a vitrified ring wheel should be used, because the scale is destructive to cloth or abrasive circles. When using the ordinary steel disk wheel, the entire surface of the work is usually ground at once, and the part is allowed to "float" against the grinding disk and is not held rigidly. When ring wheels are used, the work is usually held rigidly and is fed across the face of the grinding wheel by an oscillating movement of the work-table. The wheels used are bonded by the vitrified process, and carbide of silicon abrasives, such as carborundum, crystolon, etc., are ordinarily used for such metals as cast iron and brass, whereas, aluminum-oxide abrasives, such as alundum and aloxite, are used for steel or malleable iron parts.

The abrasive cloth disks have proved the economy of disk grinding a great many machine parts, as far as the time required for finishing is concerned, but their wider application for finishing work on the disk grinder has been retarded, because of the high cost of the abrasive cloth disks, due to the cloth, glue, emery, and labor that enter into their manufacture. It is claimed that the solid ring and disk wheels can successfully replace cloth disks for practically all classes of work excepting in some cases, operations requiring the use of the finer grained disks from No. 46 up.

The ring wheel must not be confused with a wide-faced solid wheel, which has a comparatively small hole through the center. A ring wheel is one that has a working face of from 1 to 4 inches. All work ground on these wheels must be securely fastened in a jig or fixture when passed across the face of the wheel, whereas, "floating" or applying the work free-hand to the face of the wheel is the method employed when a wide-faced wheel or disk is used. The wider faced ring wheels, with a working face of from 3 to 4 inches or more, are well adapted for work that is ground on surface grinders of the "face" or "edge" type, which are usually supplied with a wheel having a 2-inch working face.

The larger sizes of single-head disk grinding machines, fitted with 18- or 20-inch ring wheels and having a geared lever-feed table, are preferable to the 24-inch edge grinder for handling small or medium sizes of work.

Ring wheels are used on both the single-spindle and double-spindle machines. When using the double-spindle type, foot levers are desirable for bringing the grinding wheels in contact with the work, as the operator has the use of both hands for holding the part being ground. The foot-lever feed is not recommended when steel disk wheels are used, because disk wheels should be fed against the work carefully, which is not readily done by means of a foot lever. For finishing work that must be ground to close limits, it is preferable to use the double-spindle machine with one head locked, the feeding movement being confined to the other head; there is likely to be some lost movement in each head and the error due to lost movement is greatly reduced by holding one of the heads stationary. The work may easily be ground within a limit of 0.003 inch when this precaution is taken. Some double-spindle grinders are equipped with a sliding table attachment for grinding parts which must have accurate parallel sides.

Grain and Grade of Wheels. — The grain and grade of ring wheels depend not only upon the kind of material to be ground but also upon the area of the ground surface. For grinding steel or malleable iron parts, with a surface of 2 square inches or more to be finished, a grain 16, grade N, vitrified, alundum wheel may be used. For smaller areas, which must be ground to within a limit of 0.003 inch or less, a grain 20, grade P wheel is suitable. For securing a finer finish on steel, a 36- to 46-grain, alundum wheel of grade O or P can be used. Such wheels are not recommended for fast cutting; they are only suitable for those classes of work where a No. 46 grain cloth disk would give satisfactory results.

For grinding cast iron or brass, a grain 24, grade M to H, carborundum wheel may be used. A grain 24, grade M, crystolon wheel has given satisfactory results on gray iron castings. Ring wheels should be rather harder than solid wheels for the same class of work.

To secure a fine finish on small brass nuts or similar work, a carborundum wheel of 36 to 60 grain, grade M, will be found satisfactory.

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